A GUIDE TO THE LITERATURE ON CARBON DIOXIDE LASERS (1 JANUARY 1964 - 30 JUNE 1968)

John H. McElroy, et al

Goddard Space Flight Center
Greenbelt, Maryland

November 1968

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A GUIDE TO THE LITERATURE ON CARBON DIOXIDE LASERS (1 January 1964 - 30 June 1968)

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NOVEMBER 1968

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

This document presents the results of a literature search on carbon dioxide lasers through twenty-three scientific and technical journals and the NASA Scientific and Technical Aerospace Reports (STAR) for the period 1 January 1964 through 30 June 1968. The results are presented in a chronological listing in which each item contains three sections: (1) a standard bibliographical listing, (2) an abstract of the paper or article, and (3) a comprehensive listing of keywords or phrases extracted from the publication. Over 138 references by 169 authors are included. This listing is followed by an alphabetical listing of the authors with their publications referenced to their chronological order number. The third listing, consisting of 280 items, gives, in alphabetical order, the extracted keywords and phrases referenced to the articles by the chronological reference numbers. This document will reduce considerably the time required to search the literature on carbon dioxide lasers or to find the value of a particular parameter of the laser.

CONTENTS

A GUIDE TO THE LITERATURE ON CARBON DIOXIDE LASERS
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1. INTRODUCTION

The carbon dioxide laser has proven itself to be one of the most important technological developments of recent years. Since Patel, Faust, and McFarlane announced the attainment of milliwatt powers from a continuous-wave gas laser employing carbon dioxide as the active medium, the carbon dioxide laser has undergone an astonishing period of development. This development has proceeded along two separate, but related, paths. The first of those paths has been the pursuit of higher and higher power outputs. This has culminated in recent months with the attainment of multikilowatt continuous laser beams, a growth of more than six orders of magnitude in less than five years. The second path has been the search to find techniques to control and harness the raw power made available by this remarkable laser. This path has also led to significant achievements. It is now possible to speak of frequency stabilities on the order of parts in 10^{13} and small, efficient sources of energy that can be employed as transmitters and local oscillators in spaceborne communications systems.

As must inevitably happen when such an interesting device appears, the quantity of literature of the carbon dioxide laser swelled and cascaded until the maintenance of a file of information on the laser became a formidable and often unrewarding task. The Optical Systems Branch has been active in carbon dioxide laser research for a number of years and has, of necessity, accumulated a large quantity of reprints, preprints, papers, articles, and reports. In the evaluation of proposals and the preparation of proposals, as well as in the day-to-day research activities of the branch, it was and is frequently necessary to search for an article, perhaps rather vaguely remembered, in order to find the value of a parameter of the CO_2 laser, a measurement technique, or a construction detail. The mass of available data made this a difficult and tiresome task. This document has resulted from an attempt, which has proven to be at least partially successful, to circumvent this task.

The following document consists of four sections: (1) A bibliography of review material—articles and books which give a panoramic view of the carbon dioxide laser and which can be used as a first stopping-place in a search for information or a brief summary of CO_2 laser principles. (2) An annotated chronological listing of the articles on the CO_2 laser which have appeared in twenty-three scientific or technical journals during the period 1 January 1964 through 30 June 1968. This listing includes the standard bibliographic item, an abstract of the article (usually the author's abstract, when it is available), and a number

of keywords or phrases extracted from the article which describe its contents. Each of the articles is numbered and the assigned number is used in the remainder of this document to identify the article in question. In addition to journal articles, an effort was made to survey the federal government's unclassified efforts in this area. The National Aeronautics and Space Administration publishes a semimonthly abstract journal entitled Scientific and Technical Aerospace Reports which includes a comprehensive coverage of scientific and technical reports published by NASA and its contractors as well as scientific and technical reports of other government agencies, universities, and research organizations throughout the world. All work mentioned in this journal during the period in question has been included in this document. (3) An alphabetical listing of all authors whose works appear in the preceding section with a listing of the reference numbers of their publications. (4) An alphabetical index of the keywords and phrases which characterize the various articles and which were extracted in the second section. It is hoped that a researcher will be able to materially shorten the time required for him to locate the references giving a particular parameter.

The following journals were searched in the preparation of this document:

1. American Journal of Physics
2. Applied Optics
3. Applied Physics Letters
4. Bell System Technical Journal
5. Electronic Engineering
6. Infrared Physics
7. IEEE Journal of Quantum Electronics
8. IEEE Transactions on Antennas and Propagation
9. IEEE Transactions on Electron Devices
10. Journal of Applied Physics
11. Journal of Molecular Spectroscopy
12. Journal of the Optical Society of America
13. Philips Research Reports and Supplements

14. Philips Technical Review
15. Physica
16. Physical Review
17. Physical Review Letters
18. Physics Letters
19. Proceedings of the IEEE
20. Proceedings of the Royal Society
21. Soviet Physics - JETP
22. Soviet Physics - Technical Physics
23. Soviet Physics - Uspekhi

The following issues of Scientific and Technical Aerospace Reports (STAR) were searched: N64-10 001, Vol. 2, No. 1, January 8, 1964 through N68-23 044, Vol. 6, No. 12, June 23, 1968.

It was decided not to continue the search into journals in languages other than English since most of the significant work has been reported in English and that which has been published in other languages can be obtained second-hand from articles written in English. This restriction was imposed because of the practical limitations which had to be placed on the time and effort devoted to this task. Unfortunately, such a restriction must slight the work of a number of highly competent researchers. The French performed some of the earliest work on the carbon dioxide laser and this has not been thoroughly searched or acknowledged. Four of the early articles which may be useful to the researcher are:

Legay-Sommaire, N., L. Henry, and F. Legay: Réalisation d'um laser utilsont l'energie de vibration des gaz excites par l'azote activé (CO, CO_2, et N_2O). Academie Des Sciences, Comptes Rendus, Paris, t. 260, Groupe 6, March 22, 1965, pp. 3339-3342.

Barchewitz, P., L. Dorbec, R. Farrenq, A. Truffert, and P. Vautier: Émission infrarouge de CO et CO_2 et laser continu á CO_2 par action directe d'une excitation haute frequence. Academie Des Sciences, Comptes Rendus, Paris, t. 260, Groupe 6, March 29, 1965, pp. 3581-3582.

Barchewitz, P., L. Dorbec, A. Truffert, and P. Vautier: Émission laser continu par excitation haute fréquence directe de CO_2 et N_2O dans les transitions vibrationnelles 00°1-10°0 et 00°1-02°0. Academie Des Sciences, Comptes Rendus, Paris, t. 260, Groupe 6, May 24, 1965, pp. 5491-5493.

Farrenq, R., C. Meyer, C. Rosetti, L. Dorbec, and P. Barchewitz: Amplification du rayonnement d'un laser á CO_2 par du gaz carbonique excité en haute fréquence. Academie Des Sciences, Comptes Rendus, Paris, t. 261, Groupe 6, October 4, 1965, pp. 2617-2620.

Another article which appeared in a journal that was not searched that is very useful is:

Patel, C. K. N.: Recent Developments in CO_2 and Other Molecular Lasers. J. de Chime Physique et de, Vol. 64, No. 1, January 1967, pp. 82-92.

Other European and Japanese journals have likewise not been given fair treatment in this search. The journals printed in Japanese were beyond the grasp of the branch members involved in the search and the Japanese journals printed in English were generally unavailable. One useful article, however, is:

Shimazu, M., Y. Suzaki, M. Takatsuji, and K. Takami: Q-Switched CO_2 Laser and the Detection with the Pyroelectric Thermal Detector. Japanese Journal of Applied Physics, Vol. 6, No. 1, January 1967, p. 120.

It is almost inevitable that omissions or errors have crept into this work. The compilers regret all mistakes and earnestly seek corrections and additions so that this listing may be as accurate as possible. Suggestions and comments can be sent to them through the Optical Systems Branch, Mail Code 524, Goddard Space Flight Center, Greenbelt, Maryland, 20771.

2. REVIEW MATERIALS

A chronological listing of review articles relating in total or in part to the carbon dioxide laser follows. In some cases these are repeated in the following section when they appear in journals covered in the search.

Rigden, J. D., and G. Moeller: Recent Developments in CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-2, No. 9, September 1966, pp. 365-368.

Bloom, A. L.: Gas Lasers. Proceedings of the IEEE, Vol. 54, No. 10, October 1966, pp. 1262-1276.

Patel, C. K. N.: Recent Developments in CO_2 and Other Molecular Lasers. J. de Chime Physique et de, Vol. 64, No. 1, January 1967, pp. 82-92.

Whitehouse, D. R.: Understanding CO_2 Lasers. Microwaves, Vol. 6, No. 7, July 1967, pp. A6-A14.

Gullberg, K., B. Hartmann, E. Kock, and B. Tengroth: Carbon Dioxide Laser Hazards to the Eye. Nature, Vol. 215, No. 5103, August 19, 1967, pp. 857-858.

Tychinskii, V. P.: Powerful Gas Lasers. Soviet Physics - Uspekhi, Vol. 10, No. 2, September - October 1967, pp. 131-152.

Sobolev, N. N. and V. V. Sokovikov: CO_2 Lasers. Soviet Physics - Uspekhi, Vol. 10, No. 2, September - October 1967, pp. 153-170.

McElroy, J. H.: The CO_2 Laser. Electronics World, Vol. 79, No. 5, May 1968, pp. 46-48, 77.

Patel, C. K. N.: High-Power Carbon Dioxide Lasers. Scientific American, Vol. 219, No. 2, August 1968, pp. 22-33.

In addition to these articles, several of the more recent books dealing with lasers have sections concerning the carbon dioxide laser. Two of these are:

Garrett, C. G. B.: Gas Lasers. McGraw-Hill Book Co., Inc., 1967.

Bloom, A. L.: Gas Lasers. John Wiley & Sons, Inc., 1968.

3. ANNOTATED CHRONOLOGICAL BIBLIOGRAPHY

The following bibliography lists the papers pertaining to the carbon dioxide laser in chronological order. In several cases, papers which do not pertain directly to the carbon dioxide laser have been included when they are so closely related that their omission would leave gaps in the chronological development. Each paper has been assigned a reference number in accordance with its chronological position. These numbers are employed in the index to identify the papers.

1. Patel, C. K. N., W. L. Faust, R. A. McFarlane, and C. G. B. Garrett: Laser Action up to 57.355 Microns in Gaseous Discharges (Ne, He-Ne). Applied Physics Letters, Vol. 4, No. 1, January 1, 1964, pp. 18-19.

   Abstract: Reports laser action in pure Ne and in Ne-He discharges at nine wavelengths between 31.928 and 57.355 microns. Six of these wavelengths, ranging from 35.602 to 57.355 microns, belong to the 7p - 6d group of Ne. The remaining three, from 31.928 to 41.741 microns, are in the 6p - 5d group.

   Keywords: Hole (Aperture) Coupling, Cavity configurations

2. Patel, C. K. N., R. A. McFarlane and W. L. Faust: Optical Maser Action in C, N, O, S, and Br on Dissociation of Diatomic and Polyatomic Molecules. Physical Review, Vol. 133, No. 5A, March 2, 1964, pp. A1244-A1248.

   Abstract: This paper reports cw optical maser action in carbon, nitrogen, oxygen, sulfur, and bromine. The maser action is obtained on dissociation of various diatomic and polyatomic gases. The transitions reported here cover a wavelength range from 8400 Å to 15 000 Å. The optical-maser action on the carbon line is obtained on dissociation of CO or CO_2 in a discharge containing CO or CO_2 with either helium or neon. Maser oscillation in nitrogen was obtained from a discharge containing NO or N_2O with helium or neon. In both cases above, i.e., in the cases of carbon and nitrogen, the discharges also exhibited maser action on an atomic oxygen line. A discharge containing SF_6 or SF_6 with helium produced maser action in sulfur. And bromine + argon discharge yielded maser oscillation at four separate wavelengths spaced very closely around 8446 Å, which were

resolved with a 1-m Jarrell-Ash spectrometer. These four wavelengths in the Br_2 + Ar maser may be of special interest in microwave beat experiments because the separations between them are 3.92, 13.90, 3.78, and 21.60 GHz, respectively. A detailed description of possible dissociation and excitation mechanisms which lead to the above masers is given.

Keywords: Spectroscopy, CO_2 Dissociation, Line Strength

3. Faust, W. L., R. A. McFarlane, C. K. N. Patel, and C. G. B. Garrett: Noble Gas Optical Maser Lines at Wavelengths Between 2 and 35 Microns. Physical Review, Vol. 133, No. 6A, March 16, 1964, pp. A1476-A1486.

Abstract: This paper describes studies of the stimulated emission spectra of Ne, Ar, Kr, and Xe with Ge:Au, Ge:Cu, and Ge:Zn photodetectors. Term assignments are given (with alternatives specified in cases of ambiguities) for sixty newly observed or newly identified wavelengths of Ne, twenty-six of Ar, sixteen of Kr, and four of Xe. Only in the case of nine of the Ne lines (5s - 4p) may the pumping of atoms to the upper maser level be attributed to energy transfer from metastable atoms of a different gas (He $2s^1S_o$ atoms). For the other lines the excitation may occur through electron impact upon atoms in the ground state or in the lowest s levels, or it may occur through processes of recombination and/or cascade. Some interesting regularities which appear among the observed lines are pointed out.

Keywords: Spectroscopy, Physical Structure of Laser, Line Strength, Spectral Lines

4. Patel, C. K. N., W. L. Faust, and R. A. McFarlane: CW Laser Action on Rotational Transitions of the $\Sigma_u^+ - \Sigma_g^+$ Vibrational Band of CO_2. Bulletin of the American Physical Society, Vol. 9, No. 4, April 27, 1964, p. 500.

Abstract: The authors have obtained cw optical-maser action on a number of rotational transitions of the $\Sigma_u^+ - \Sigma_g^+$ vibrational bands of CO_2. The upper laser level Σ_u^+ is 00°1. The lower laser level Σ_g^+ is 10°0 and 02°0. (10°0 and 02°0 levels are separated by 102.8 cm^{-1} owing to Fermi resonance.) The 00°1-10°0 band has its center at 961.03 cm^{-1} (10.41 microns) and the 10°0-02°0 band is centered at 1063.87 cm^{-1} (9.40 microns). Laser action is obtained on the rotational transitions in the negative branch of both of the bands. A preliminary wavelength measurement indicated a close check with previously made measurements of wavelengths made in absorption. The optical-maser power output on these transitions is high enough to be able to improve the wavelength determinations substantially.

Keywords: Laser Action on Rotational Transitions

5. Patel, C. K. N.: Interpretation of CO_2 Optical Maser Experiments. Physical Review Letters, Vol. 12, No. 21, May 25, 1964, pp. 588-590.

Abstract: This paper presents a simple theoretical treatment which allows one to interpret previously reported results, especially the fact that no R-branch transitions are seen in CO_2 maser oscillation. The treatment satisfactorily explains these results and leads to the conclusion that for the vibrational-rotational transitions, optical maser action can be obtained on the P-branch transitions even when no inversion exists between the total population densities in the two vibrational states.

Keyword: Population Density, Gain

6. Witteman, W. J., and R. Bleekrode: Pulsed and Continuous Molecular Far Infra-Red Gas Laser. Physics Letters, Vol. 13, No. 2, November 15, 1964, pp. 126-127.

Abstract: It is the purpose of this letter to report on pulsed and continuous operation in the far infrared with an output of the order of 1 mW under relatively mild excitation conditions and to propose an interpretation of the most prominent of the observed lines.

We developed a confocal molecular laser of 1 meter length and 3.2 cm i.d. filled with water vapor at a pressure of 0.4 torr and operating with a peak voltage of about 4 kV and an average current of about 40 ma.

Keywords: Confocal Resonator, Hole (Aperture) Coupling, H_2O Laser, Water-Vapor Laser

7. Patel, C. K. N.: Selective Excitation through Vibrational Energy Transfer and Optical Maser Action in N_2 - CO_2. Physical Review Letters, Vol. 13, No. 21, November 23, 1964, pp. 617-619.

Abstract: A report on the selective excitation of CO_2 molecules through transfer of vibrational energy of nitrogen molecules in the $\nu = 1$ vibrational level of their ground electronic state $^1\Sigma^+$, and resulting optical maser action on the rotational transitions (near 10.6 microns) of the 00°1-10°0 vibrational band of CO_2 in a continuous-flow N_2-CO_2 system is given.

Keywords: Selective Excitation, Physical Structure of Laser, Line Strength, Vibrational Energy Transfer, Wavelength Tabulation

8. Patel, C. K. N.: Continuous Wave Laser Action on Vibrational-Rotational Transitions of CO_2. Physical Review, Vol. 136, No. 5A, November 30, 1964, pp. A1187-A1193.

Abstract: This paper reports cw laser action on a number of rotational transitions of the $\Sigma_u^+ - \Sigma_g^+$ vibrational band of CO_2 around 10.4 and 9.4 microns. The laser wavelengths are identified as the P-branch rotational transitions from P(12) to P(38) for the 00°1-10°0 band and from P(22) to P(34) for the 00°1-02°0 band. Strongest laser transition occurs at 10.6324 microns (vacuum). A cw power output of about 1mW has been measured. All these laser transitions can also be made to oscillate under pulsed discharge conditions with a small increase in the peak laser power output. No R-branch transitions have been seen to oscillate either under cw or pulsed discharge conditions. The wavelength measurements are in reasonable agreement with earlier measurement of the bands in absorption, but there are slight differences. These are ascribed to possible pressure-dependent frequency shift effects. A study has been made of the time dependence of the laser output under pulsed excitation, and some conclusions about possible excitation processes are given. Theoretical interpretation given earlier for laser action on the vibrational-rotational transitions is discussed in a generalized form. The theory is applicable to both the linear polyatomic molecules and the diatomic molecules.

Keywords: Spectroscopy, Gain, Vibrational-Rotational Transitions of CO_2, Wavelength Tabulation, Spectral Line Width

9. Patel, C. K. N.: CW High Power N_2-CO_2 Laser. Applied Physics Letters, Vol. 7, No. 1, July 1, 1965, pp. 15-17.

Abstract: This paper reports cw high-power operation of a N_2-CO_2 laser oscillating on the P-branch rotational transitions of the 00°1-10°0 vibrational band of CO_2. Output powers of about 11.9 watts on two transitions near 10.6 microns were obtained. The stronger of the laser transitions has about 75% of the power output. Efficiency of converting dc discharge power into laser power is about 3%.

Keywords: High Power Output, Efficiency

10. Howe, J. A.: Effects of Foreign Gases on the CO_2 Laser: R-branch Transitions. Applied Physics Letters, Vol. 7, No. 1, July 1, 1965, pp. 21-22.

Abstract: It has recently been reported that laser action may be obtained on the P-branch of the CO_2 00°1-10°0 band. Patel, Faust, and McFarlane found a large number of lines to be excited by a pulsed discharge in pure CO_2. Subsequently, Patel showed that a mixture of a stream of discharged active nitrogen with flowing CO_2 produced continuous oscillation on a number of lines. In the course of work on the N_2/N_2O system, Patel also found that addition of N_2 to the N_2O stream before it entered the discharge region produced additional laser transitions in the N_2O.

In order to see if similar effects occur in the case of CO_2, flowing mixtures of CO_2 with various other gases have been examined. It is the purpose of this paper to present these results, and to discuss their implications concerning the inversion mechanism. Further, it has been found that suitable mixtures also produce laser action on various transitions of the R-branch.

Keywords: Additives (N_2, air, CO, H_2, O_2, N_2O, C_2H_2, C_2H_4), R-branch Transitions, Foreign Gas Effects, Line Strength

11. Witteman, W. J.: Increasing Continous Laser-Action on CO_2 Rotational Vibrational Transitions through Selective Depopulation of the Lower Laser Level by Means of Water Vapour. Physics Letters, Vol. 18, No. 2, August 15, 1965, pp. 125-127.

Abstract: Recently the operation of a continuous CO_2 laser using a dc discharge in a 5 m laser tube and a gas pressure of 0.8 Torr has been described. The laser oscillations were found in both 00°1-10°0 and 00°1-02°0 bands. Besides this experiment with dc discharges, some authors have reported continuous laser action in CO_2 through selective excitation transfer from N_2^* which was excited by an rf discharge while streaming fast.

This paper reports on continuous laser action in a closed system during dc discharge in a laser tube of only 1 m length and an internal diameter of 30 mm filled with purified CO_2, CO_2 with H_2O, CO_2 with N_2, and also a mixture of CO_2, N_2, and H_2O. It also describes the prominent part played by water vapour in depopulating the lower laser level.

Keywords: Additive (water vapor), Selectivc Depopulation of Lower Laser Level, Closed (Sealed-Off) System, Doppler Line Width

12. McFarlane, R. A. and J. A. Howe: Stimulated Emission in the System CO/CO_2. Physics Letters, Vol. 19, No. 3, October 15, 1965, pp. 208-210.

Abstract: Laser oscillations on various rotational transitions of a number of vibrational bands has been reported for CO_2 and CO. This report describes new laser transitions in flowing streams of pure CO_2 and in CO_2 mixed with CO, using high current pulsed dc excitation. The authors also report new CO transitions observed in both pure CO_2 and CO_2/CO mixtures. Several new CO_2 transitions were observed in pure CO_2 and additional CO_2 transitions were observed in CO_2/CO mixtures.

Keywords: Mixtures of CO_2/CO, Spectroscopy, Wavelength Tabulation

13. McAvoy, N.: 10.6 Micron Communication System. Goddard Space Flight Center. NASA TM X-524-65-461, November 1965.

Abstract: Extensive investigation has been made by industrial concerns and NASA personnel on the utilization of lasers for NASA deep space communication requirements. Most of this analysis has been speculative in that it has been made on projected development of new lasers, new optical receivers, new modulators, improved tracking telescopes, and large diffraction limited optics. The analysis made herein and the resulting proposed communication system is based on either equipment which is presently available or equipment which is to be modified by tried and proven methods. It is felt that the experiment to be discussed in conjunction with similar experiments on the optical technology satellite now being studied under contract NAS8-20115 can result in sufficient know-how to design a communications transmitter and auxiliary equipment for a Mars probe which will transmit a real-time TV signal to earth.

Keywords: Deep-space Communication, Detection, Optical Receivers

14. Bridges, T. J., and C. K. N. Patel: High Power Brewster Window Laser at 10.6 Microns. Applied Physics Letters, Vol. 7, No. 9, November 1, 1965, pp. 244-245.

Abstract: This letter reports on a Brewster window laser with stationary gas fills of pure CO_2 and CO_2 with N_2 which obtained high cw power output (2 - 5 watts) and high efficiency (2 - 5%) around 10.6 microns. The seven laser lines observed belong to the P-branch of the 00°1-10°0 vibrational-rotational band of CO_2. Many of the lines could be obtained alone in a single longitudinal mode of the resonator. As expected, a significant increase in output was obtained on cooling the tube wall to -60°C.

Keywords: Additive (N_2), Sealed-off System, Cooled Tube Walls, Efficiency, Gain

15. Patel, C. K. N.: CW Laser Action on Vibrational-Rotational Transitions of CO. Applied Physics Letters, Vol. 7, No. 9, November 1, 1965, pp. 246-247.

Abstract: This paper presents the first precise measurements of vibrational-rotational transition frequencies ($6 \leq \nu \leq 18$) of the $X^1\Sigma^+$ state of CO ($\pm 0.02\,cm^{-1}$).

Keywords: Spectroscopy, Vibrational-Rotational Transitions of CO

16. Moeller, G. and J. D. Rigden: High-Power Laser Action in CO_2-He Mixtures. Applied Physics Letters, Vol. 7, No. 10, November 15, 1965, pp. 274-276.

Abstract: The purpose of this letter is to report enhanced power output of dc excited CO_2 lasers by the addition of He to the discharge, both in flowing and non-flowing systems. Power outputs of 62 mW per cc have been observed. It has been found that He added to CO_2 has a larger effect on laser power output than the addition of N_2, and that best results are obtained in a tube containing a flowing mixture of CO_2, He, and N_2. Cooling the discharge tube with forced air is found to increase the output power markedly in the flowing gas system.

Keywords: Sealed-off System, Additives (He, N_2), Cooling (Forced Air), Efficiency, Cavity Power Density

17. Patel, C. K. N., P. K. Tien, and J. H. McFee: CW High-Power CO_2-N_2-He Laser. Applied Physics Letters, Vol. 7, No. 11, December 1, 1965, pp. 290-292.

Abstract: This letter reports that the addition of large amounts of helium is desirable in order to obtain high-power output from a large diameter CO_2-N_2 laser.

Keywords: Additives (He, Ne, Ar), Large Diameter Tube

18. Jastrzebski, Z. D.: Development of the 10.6 Micron Laser. Lafayette College, Easton, Pa., NASA Summer Fellowship Program, CFSTI Doc. No. N66-31161, January 1966.

Abstract: Work was initiated on the development of a 10.6 micron nitrogen-carbon dioxide laser to be used in an optical tracking system for communication between the ground stations and the Echo II satellite. Two experimental setups, which, with respect to the Vycor discharge tube, differed in the mirror arrangement, were designed. In one

setup the gold-plated mirrors form an integral part of the laser assembly, being vacuum tight connected to the ends of the discharge tube through metallic bellows. In the second the gold plated mirrors are located external to the discharge tube, which is terminated by vacuum tight Brewster-angle windows. These windows and one of the two gold-plated mirrors are made of barium fluoride. This mirror has a one millimeter diameter hole in the gold coating for coupling out the radiation; the other mirror is 100% opaque. The discharge tube is connected through an outlet with the manifold of the vacuum system so that it is possible to control precisely low partial pressures of the gaseous ingredients. Quantitative measures for the detection of the infrared beam were performed.

Keywords: Communications, Optical Tracking, Aperture Coupling, Detection

19. Howe, T. A. and R. A. McFarlane: New Emission Systems in CO_2. Journal of Molecular Spectroscopy, Vol. 19, No. 2, February 1966, pp. 224-226.

Abstract: This note discusses the experimental arrangement and reports the results of precise wavelength determinations for sixteen members of a $\pi - \pi$ band near 11 microns. Evidence for the assignment of the observed lines to the P-branch of the $01^1 1\text{-}11^1 0$ band is given.

Keywords: Spectroscopy, Near-confocal Resonator, Additives (N_2), Spectral Line Width, Doppler Line Width

20. Kovacs, M. A., G. W. Flynn, and A. Javan: Q-Switching of Molecular Laser Transitions. Applied Physics Letters, Vol. 8, No. 3, February 1, 1966, pp. 62-63.

Abstract: This report describes the optimum Q-switching performance of several molecular gas lasers (CO_2, N_2O, CO_2-N_2, CO_2-N_2-He). It further reports on the optimum gas pressures for Q-switching versus cw operation.

Keywords: Q-Switching

21. Flynn, G. W., M. A. Kovacs, C. K. Rhodes, and A. Javan: Vibrational and Rotational Studies Using Q-Switching of Molecular Lasers. Applied Physics Letters, Vol. 8, No. 3, February 1, 1966, pp. 63-65.

Abstract: For molecular rotation-vibration laser levels, a knowledge of the time constants for decay of vibrational levels and for thermalization of rotational levels is of considerable importance. In general, the intensities of spontaneous emission originating from molecular transitions in the infrared are weak and hence not useful in the study of very fast relaxation processes. However, the use of Q-switching techniques provides a powerful means for the investigation of such processes, as reported in this letter for studies of vibrational and rotational relaxations in the CO_2 and N_2O laser systems.

Keywords: Lifetime of Vibrational Levels, Q-Switching, Thermalization of Rotational Levels

22. Moeller, G. and J. D. Rigden: Observation of Laser Action in the R-branch of CO_2 and N_2O Vibrational Spectra. Applied Physics Letters, Vol. 8, No. 3, February 1, 1966, pp. 69-70.

Abstract: Laser action has previously been reported on several lines in the P-branch of the 00°1-10°0 and 00°1-02°0 vibrational bands of CO_2 and in the 00°1-10°0 band of N_2O. In this letter we wish to report laser action on all the rotational lines in the above-mentioned CO_2 and N_2O bands in both the P and R-branches up to J values of over 50 in some cases. The two lines nearest the center of the 00°1-10°0 band of N_2O were not seen. We have seen oscillation on 170 lines, of which at least 120 had not been reported before in the literature. Of the total number of lines, 103 are in CO_2 and the rest in N_2O.

Keywords: Diffraction-grating resonator, Selective Oscillation

23. McCubbin, Jr., T. K., R. Darone, and J. Sorrell: Determination of Vibration-Rotational Line Strengths and Widths in CO_2 Using a CO_2-N_2 Laser. Applied Physics Letters, Vol. 8, No. 5, March 1, 1966, pp. 118-119.

Abstract: The authors report that they determined the strength of the 10.4 micron CO_2 band by observing the curves of growth for several rotational lines and by a new method using a laser. The laser technique also yields an accurate value of the self-broadened collision half width. The measurements were made using a 2.5 m echelle-prism spectrometer with a thermocouple detector and a White multiple reflection cell that could provide paths up to 18.10 m in multiples of approximately 2.67 m. The CO_2-N_2 laser was similar to one described by Patel differing principally in dimensions and materials.

Keywords: Spectroscopy, Line Strength, Hole Coupling, Doppler Line Width, Spectral Line Width

24. Frapard, C., M. Roulot, and X. Ziegler: High Peak Power Pulsed 10 Micron CO_2 Laser. Physics Letters, Vol. 20, No. 4, March 1, 1966, pp. 384-385.

Abstract: The authors obtained high intensity laser radiation from pure CO_2 at 10.6 microns with a sealed tube excited by high voltage pulses. Similar results have been obtained with a mixture of CO_2-N_2-He.

Keywords: Additive (He), Hole Coupling, Laser Pulse Widths, Sealed System

25. Horrigan, F.: High Power Gas Laser Research. Final Technical Report, June 15, 1965 - March 14, 1966, CFSTI Doc. No. AD 637023.

Abstract: This report discusses the investigation and optimization of a high-power high-efficiency cw gas laser utilizing a dc discharge excited, flowing mixture of carbon dioxide, nitrogen, and helium as the active laser medium. Continuous laser powers of 50 to 60 watts per meter length of active medium have been obtained in well-collimated beams at various wavelengths in the neighborhood of 10.6 microns with an efficiency of more than 10 percent.

The work involved optimization via variation of the parameters, i.e., gas flow rates, partial pressures of component, discharge current, optical coupling, additives, etc., as well as studies of: a) optical materials suitable for 10 micron radiation of the relative merits of various optical coupling schemes, i.e., diffraction coupling, transmission coupling,

dielectric films, etc., b) the variations of single pass gain with the parameters, c) the role of electrochemical effects, i.e., dissociating, recombination, etc., d) the lifetimes of the laser level via direct afterglow investigation, e) spectroscopy in both the visible and the infrared, and f) Q-spoiling.

A detailed picture of the operating principles of the CO_2 laser is presented along with estimates of the ultimate powers (several watts per cc of active medium) and efficiencies (20 to 40%) obtainable and an indication of those aspects that are least understood and deserving of future effort.

Keywords: Coupling, Electrochemical Effects, Laser Level Lifetimes, Spectroscopy, Q-Switching, Single-pass Gain, Optical Materials, Cavity Power Density, Efficiency, Additives (N_2, He)

26. Wieder, I. and G. G. McCurdy: Isotope Shifts and the Role of Fermi Resonance in the CO_2 Infrared Maser. Physical Review Letters, Vol. 16, No. 13, March 28, 1966, pp. 565-567.

Abstract: In this letter the authors report the observation of laser action in several P transitions of the 00°1-10°0 and 00°1-02°0 bands of $C^{12}O_2^{18}$. The letter also points out the contribution of Fermi resonance to the large observed isotope shift and the importance of Fermi resonance to the kinetics of the laser.

Keywords: Fermi Resonance, Isotopes

27. Patel, C. K. N: Optical Harmonic Generation in the Infrared Using a CO_2 Laser. Physical Review Letters, Vol. 16, No. 14, April 4, 1966, pp. 613-616.

Abstract: In this paper the author reports optical harmonic generation in the infrared in (a) zinc blende crystals (43m), InAs, GaAs, ZnS, CdTe, ZnSe, and ZnTe; (b) hexagonal crystals (6mm), ZnS, CdS, and CdSe; and (c) a trigonal crystal (32), Se.

Keywords: Optical Harmonic Generation, Nonlinear Coefficient Measurements, Hole Coupling

28. Gerry, E. T. and D. A. Leonard: Measurement of 10.6 Micron CO_2 Laser Transition Probability and Optical Broadening Cross Sections. Applied Physics Letters, Vol. 8, No. 9, May 1, 1966, pp. 227-229.

Abstract: This letter describes some simple measurements of absorption in CO_2 and mixtures of CO_2 and other gases employing a cw 10.6 micron laser as a source of resonant radiation. Analysis of the absorption coefficient yields several quantities of interest: (1) the optical transition probability for the (001) to (100) carbon dioxide laser transition, and (2) optical broadening cross sections for this transition for collisional broadening by CO_2 and other molecules. Knowledge of these quantities allows measurements of gain in operating systems to be directly interpreted in terms of inversion density.

Keywords: Transition Probabilities, Optical Broadening Cross Sections, Absorption Coefficient, Spectroscopy, Gain

29. Aerospace Group, Hughes Aircraft Company: Parametric Analysis of Microwave and Laser Systems for Communication and Tracking. Contract No. NAS5-9637, Report No. P66-135, HAC Reference No. A7747, Third Quarterly Report, June 6, 1966.

Abstract: This report compares the communication capability of microwave and laser systems for deep-space missions. This particular quarterly report contains a useful summary of the knowledge of CO_2 laser characteristics as of that date.

Keywords: Communication, Spectroscopy, Physical Construction of Laser, Wavelength Tabulation, Doppler Line Width

30. Rosenberger, D.: The Influence of Hydrogen on the Output of a N_2-Co_2 Laser. Physics Letters, Vol. 21, No. 5, June 15, 1966, pp. 520-521.

Abstract: The power of a N_2-CO_2 laser is considerably enhanced by the addition of H_2. The effect is due to the created H_2O as well as to excited H_2 molecules.

Keywords: Additive (H_2)

31. Walsh, T.: Development of a 10.6 Micron Laser Modulator, Final Report. RCA, Microwave Applied Research Laboratory, Contract NAS5-10144, July 18, 1966.

Abstract: Electro-optic modulation crystal growth and properties, and design equations and performance are reported for a 10.6 micron laser modulator of gallium arsenide. The constructed GaAs modulator gives 61% depth of modulation for 1000 volts peak modulating signal over a bandwidth from dc to more than 20 MHz. Efficient and compact quarter wave plates and polarizers were developed for use at the 10.6 micron wavelength.

The modulator was used to measure the electro-optic coefficient of GaAs crystal between parallel polarizers. A thick CdS wave plate, also placed between the polarizers, was oriented with its fast axis at 45° to the plane of passage of the polarizers. Phase retardation increased as the wavelengths became shorter.

Keywords: Electro-optic Modulator, GaAs Modulator, Phase Retardation

32. Hocker, L. O., M. A. Kovacs, C. K. Rhodes, G. W. Flynn, and A. Javan: Vibrational Relaxation Measurements in CO_2 Using an Induced-Fluorescence Technique. Physical Review Letters, Vol. 17, No. 5, August 1, 1966, pp. 233-235.

Abstract: This letter is a summary of preliminary experimental studies of a number of relaxation processes involving excited vibrational levels of the CO_2 molecule. These studies involve the use of a new technique in which infrared fluorescence, induced by the application of intense pulses of Q-switched 10.6 micron laser radiation, is used to obtain an accurate measure of the rate of volume quenching of the first excited asymmetrical stretching mode (00°1) of the CO_2 molecule.

Keywords: Q-Switching, Fluorescence, Relaxation Processes

33. Reynolds, R. S., A. E. Siegman, J. D. Foster, and R. Rogers: Frequency-Stabilized CO_2 Lasers. Sylvania Electronic Systems - Western Operation, Phase One Report, Contract NAS8-20631, August 12, 1966.

Abstract: This report covers the work performed in a study effort to establish the best techniques for attaining a $1:10^{10}$ frequency-stabilized CO_2 laser. The report discusses several electronic and mechanical stabilization schemes, control loop techniques, wavelength and mode control techniques, and general laser construction and operation approaches. It appears that a technique which stabilizes the CO_2 laser frequency to an external CO_2 amplifier is capable of providing the required frequency stability.

Keywords: Mechanical Frequency Stabilization, Electronic Frequency Stabilization, Wavelength Control, Piezoelectric Tuning, Mode Control, CO_2 Laser Amplifier, Physical Structure of Laser

34. Bridges, T. J: Competition, Hysteresis and Reactive Q-Switching in CO_2 Lasers at 10.6 Microns. Applied Physics Letters, Vol. 9, No. 4, August 15, 1966, pp. 174-176.

Abstract: High repetition rate (30-60 kHz) Q-Switching in a CO_2 laser at 10.6 microns is reported. A moving mirror technique using steady mirror velocities between 16 and 30 cm/sec produces one pulse of the strongest (P20) line per half wavelength of travel. The usable pulsing rate is determined by, and is a measure of, the lower laser level lifetime (approximately 30 microseconds). In a 1 watt cw laser, peak powers approximating 30 watts with pulse lengths of approximately one microsecond and average power approximately equal to the cw power were obtained. This and related competition and hysteresis effects result from strong coupling between the lines of the vibrational-rotational spectrum due to thermalizing molecular collisions.

Keywords: Q-Switching, Laser Level Lifetimes, Pulse Lengths, Rotating Mirror, Line Competition, Hysteresis Effect, Doppler Line Width

35. Rigden, J. D. and G. Moeller: Recent Developments in CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-2, No. 9, September 1966, pp. 365-368.

Abstract: Experimental results are presented showing the effect of tube diameter on the output power and efficiency of CO_2 lasers. It is shown that both output power and efficiency are almost independent of diameter over the range 11 mm to 44 mm. The measured values of the output power and efficiency are 75 watts per meter and 10 percent. Higher efficiencies are obtained at lower power outputs. Mirror damage is discussed and two experiments involving the irradiation of CO_2 and ammonia with a high power laser beam are mentioned. An explanation is given for the strong interaction between the laser beam and the discharge tube current. Finally, a flow calorimeter used to measure high power laser beams is described.

Keywords: Power Measurement Device (Flow Calorimeter), Mirror Damage, Efficiency, Power Output, Effect of Tube Diameter, Optimum Gas Mixture

36. Weber, M. J. and T. E. Deutsch: Pulsed and Steady-State Infrared Emission Studies of CO_2 Laser Systems. IEEE Journal of Quantum Electronics, Vol. QE-2, No. 9, September 1966, pp. 369-375.

Abstract: Transient and steady-state infrared emission at 2.5 to 15 microns from low-lying vibrational-rotational levels of CO_2 has been studied using a dc discharge. The time-dependent behaviors of several levels important for laser excitation and relaxation were examined following a pulsed discharge. The decays were, in general, different and were not simple exponentials. Relaxation of vibrational energy of CO_2 appears to occur by collisions involving vibration-vibration exchange between different vibrational modes and vibration-vibration relaxation of the bending mode. The rate of transfer of vibrational excitation from N_2 to various vibrational modes of CO_2 was investigated as a function of CO_2 pressure. The addition of He reduced the emission from the lower laser levels with respect to that from the upper laser level and increased the nonradiative decay rate of the lower vibrational levels by CO_2-He collisions. Under pulsed excitation, in addition to CO_2 laser action nearly coincident with the pulse, a weaker, delayed output was observed.

Keywords: Relaxation of Laser Levels, Vibration-Vibration Exchange, Additives (He, N_2), Pulsed Output

37. Witteman, W. J.: Rate Determining Processes for the Production of Radiation in High Power Molecular Lasers. IEEE Journal of Quantum Electronics, Vol. QE-2, No. 9, September 1966, pp. 375-378.

Abstract: The excitation mechanisms and relaxation processes will be described for a closed molecular gas laser of 240 cm length and 2.3 cm diameter filled with 1 Torr carbon dioxide, 2.5 torr nitrogen, and 7.2 Torr helium; the influence of adding 0.2 Torr water vapor is discussed. When all the four components are present, an output of 103 watts is reached with an efficiency of 12.5 percent. It will be argued that in the absence of water vapor the deactivation of the lower laser level is rate determining for the radiation production. However, the addition of water vapor (0.2 Torr) contributes greatly to depopulating the lower laser level by thermal relaxation, and it makes the output increase by more than a factor of two. In the latter case the vibrational excitation of the nitrogen molecules by electron impact is rate determining. We have observed that small amounts of impurities with partial pressures, sometimes less than 10^{-2} Torr, may cause a considerable decrease of radiation output. This "poisoning" effect, caused by very small impurity concentrations, can be avoided by using a discharge tube made from fused silica (quartz).

Keywords: Relaxation Mechanisms, Additive (Water Vapor), Poisoning Effect of Impurities, Recommended Tube Material

38. Flynn, G. W., L. O. Hocker, A. Javan, M. A. Kovacs, and C. K. Rhodes: Progress and Applications of Q-Switching Techniques Using Molecular Gas Lasers. IEEE Journal of Quantum Electronics, Vol. QE-2, No. 9, September 1966, pp. 378-381.

Abstract: The characteristics of a Q-Switched CO_2-N_2-He molecular laser are considered. In particular, it has been found that a 3 watt continuous system gives a Q-switch output power in excess of 10 kW per pulse. A method for determining rotational collision cross sections for CO_2 is discussed, and an induced fluorescence technique is described which is capable of giving cross sections for vibrational relaxation in CO_2. The importance of various collisional coupling mechanisms and relaxation rates in determining total cw and Q-switch output power is also considered.

Keywords: Q-Switching, Rotational Collisions, Coupling Collisions, Relaxation Rates of Laser Levels, Determination of Total Output Power, Cavity Loading

39. Koozekanani, S., J. McCoy, and D. Rensch: Inexpensive CO_2 Molecular Gas Laser. American Journal of Physics, Vol. 34, No. 10, October 1966, pp. 989-990.

Abstract: The purpose of this communication is to point out the possibility of constructing a carbon-dioxide molecular gas laser with relatively inexpensive components. It is hoped that this letter will be of interest to physics or electrical engineering laboratories that are interested in building such a laser at a reasonable cost.

Keywords: Spectroscopy, Inexpensive CO_2 Laser, Construction

40. Bloom, A. L.: Gas Lasers. Proceedings of the IEEE, Vol. 54, No. 10, October 1966, pp. 1262-1276.

Abstract: A review is given of the present status of gas discharge lasers, with particular attention to developments reported in 1965 and early 1966. Following a brief history, gas lasers are classified by types - neutral atom, ion, and molecular - and a comparison is given of the properties of the various types. A short discussion is given of noise and coherence properties. Detailed descriptions are given of three recent developments of particular interest - the CO_2 laser, the argon-ion laser, and pulsed self-terminating lasers. Finally, brief mention is made of the most important present applications of gas lasers.

Keywords: Additives (He, N_2), Laser Classifications, Single Mode (TEM_{00}), Output Beam Properties, Doppler Line Width

41. Statz, H., C. L. Tang, and G. F. Koster: Transition Probabilities Between Laser States in Carbon Dioxide. Journal of Applied Physics, Vol. 37, No. 11, October 1966, pp. 4278-4284.

Abstract: Radiative transition probabilities were investigated between certain vibrational levels of carbon dioxide. The number of levels studied was restricted to those that are directly involved in the observed laser action. Vibrational wavefunctions were determined by diagonalizing large Hamiltonian matrices (up to 30 x 30). In the Hamiltonian,

nonlinear forces were included and the potential energy contained terms up to fourth order in the normal coordinates. The dipole moment as a function of the normal coordinates was determined by comparing certain observed and calculated absorption coefficients. Reasonable agreement is obtained between theory and experiment for most transitions where experimental information is available. The radiative lifetimes of most vibrational levels were calculated to be rather long. Thus, radiative processes cannot account for relaxation times observed in laser action. Relaxation probably takes place during collisions with other molecules or light atoms. From gain measurements it is possible to determine the population difference between laser levels. In Q-switching experiments, half the energy stored in the upper maser state can be emitted in a short pulse. In thin tubes the energy content of a pulse can be 10^{-5} J/cm^3 of gas used.

Keywords: Vibrational Levels of CO_2, Radiative Transition Probabilities, Radiative Lifetimes

42. Jacoby, B. F.: A Preliminary Investigation of Laser Action Assisted by Oxidized Hydrocarbons. NASA Contractor Report 80090, Grant No. NsG-74-60, October 7, 1966.

Abstract: This report describes the apparatus constructed to investigate the possibility of new laser lines in the infrared and far infrared regions and some preliminary results are presented of a study where CO_2 and CO were generated by a chemical reaction within the discharge tube and made to lase.

Keywords: Oxidized Hydrocarbons

43. Sobolev, N. N. and V. V. Sokovikov: A Mechanism Ensuring Level Population Inversion in CO_2 Lasers. JETP Letters, Vol. 4, No. 8, October 15, 1966, pp. 204-207.

Abstract: This paper discusses the process that insures the large population of the first vibrational level of N_2 which is responsible for the population inversion of the upper laser level 00°1 of the CO_2 molecules in a CO_2-N_2 laser.

Keywords: Population Inversion, N_2 Vibrational Levels

44. Fantasia, J.: An Investigation of Critical Parameters Affecting the Lifetime of a CO_2 Laser. Honeywell Inc., Systems and Research Div., Final Report, Doc. No. HRC 66-34, November 1966.

Abstract: The work involved optimization via variations of such parameters as gas flow rates, partial pressures of component gases, discharge current, optical coupling, additives, etc. Studies were also conducted of a) optical materials suitable for 10 micron radiation, b) the role of electrochemical effects such as dissociation, recombination, etc., and c) electrode materials.

This report discusses the investigation and optimization of a high-power, high efficiency, cw gas laser utilizing a dc excited flow and non-flow mixture of carbon dioxide, nitrogen, and helium as the active laser medium. Continuous laser powers of 50 watts at 10% efficiency, flowing, and 1 to 10 watts at 1 to 10% efficiency, non-flowing, have been obtained in a 1.3 meter long tube.

Keywords: Laser Optimization, CO_2 Dissociation, CO_2 Recombination, Sealed-Off Operation, Parameter Study, High Power, Efficiency

45. Yin, P. and S. H. Koozekanani: Investigation of a Few Simple Molecular Gases as a Possible Molecular Laser Material. Ohio State University Research Foundation, Dept. of Electrical Engineering, Grant No. NsG-74-60, Report 1093-31, November 1, 1966.

Abstract: Energy levels of a few simple molecular gases which have a resonant energy level with the N_2 metastable level have been investigated for possible laser materials.

Keywords: N_2 Metastable State, Resonant Energy Level, Molecular Gases, Inversion Mechanisms

46. Clark, P. O. and M. R. Smith: An Investigation of the Effects of Gas Additives on the Electron Temperature and Density in a CO_2 Laser Discharge. Applied Physics Letters, Vol. 9, No. 10, November 15, 1966, pp. 367-369.

Abstract: The radial variation of electron temperature and density with partial gas pressures in a CO_2-N_2-He laser discharge is measured using double-probe and microwave resonance techniques. In a 22-mm-diameter discharge tube the optimum partial gas pressures for maximum laser power correspond to an electron temperature of 3eV and a density of 3×10^9 cm^{-3}. The radial electron density profile is compatible with measured gain profiles. The results indicate that the role of He in the excitation mechanism is not due to a reduction in the electron temperature.

Keywords: Electron Temperature, Electron Density, Additive (He)

47. Clark, P. O. and M. R. Smith: Pulsed Operation of CO_2-N_2-He Laser. Applied Physics Letters, Vol. 9, No. 10, November 15, 1966, pp. 369-372.

Abstract: The amplitude and time behavior of the pulsed output from a 10.6-micron CO_2-N_2-He laser is investigated as a function of partial gas pressures and discharge current. Nearly two orders of magnitude increase in output power is obtained compared to cw operation. The time behavior of the laser pulse indicates that electron excitation processes dominate in populating the upper laser level.

Keywords: Pulsed Output, Electron Excitation of Laser Levels, Single Mode (TEM_{00})

48. Rensch, D. B.: A Parameter Study of a Carbon Dioxide Gas Laser. Grant No. NsG-74-60, CFSTI Doc. No. N67-16633, November 15, 1966.

Abstract: The problem of defining some of the many parameters; such as, discharge tube width and length, gas flow rate, tube wall temperature, and gas mixtures, as they pertain to a CO_2 gas laser, is considered. The pertinent theory on symmetry properties of CO_2 and its ability to be used as an amplifying medium for infrared frequencies are presented, along with the techniques to be used in determining the effect the above-mentioned parameters have on laser action. The experimental results showed that the above parameters can be defined, therefore some of the guess-work in determining optimum laser action for a CO_2 gas laser can be removed. Also, laser operating frequency, symmetry properties, and amplifying characteristics of CO_2 can be correlated with theory.

Keywords: Parameter Study, Symmetry Properties of CO_2, Amplification, Doppler Line Width, Effect of Tube Length

49. Jacobs, G. B.: CO_2 Laser Self-Modulation Characteristics. Applied Optics, Vol. 5, No. 12, December 1966, pp. 1960-1961.

Abstract: The purpose of this letter is to point out the wide range of frequencies and high percentages of self modulation obtainable from the CO_2 laser useful for measuring such things as the response of detectors or the propagation characteristics of the atmosphere.

Keywords: Self-Modulation of CO_2 Laser, Mode Beats (Frequencies)

50. Mocker, H. and H. Gustafson: A Frequency Stabilized Carbon Dioxide Laser. Honeywell Report 12044-FR 1, Final Report, Contract No. NAS8-20645, December 22, 1966.

Abstract: This report relates the results obtained during the half-year contract NAS8-20645, "A Frequency Stabilized Carbon Dioxide Laser."

The objective of this contract was to find and demonstrate experimentally a frequency discriminant that will allow stabilization of a carbon-dioxide laser to 1 part in 10^{10} in frequency (phase 1) and to submit a design concept for the construction and evaluation of two carbon dioxide lasers having the above stated frequency stability (phase 2).

Keywords: Frequency Stabilization, Laser Construction, Doppler Discharge Tube

51. McGee, J. D.: Visual Display of Infrared Laser Output on Thermographic Phosphor Screen. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 1, January 1967, p. 31.

Abstract: This letter reports that heat sensitive phosphors have been found to be useful for visibly displaying the output patterns from infrared lasers with wavelengths from 0.97 to 28 microns.

Keywords: Heat Sensitive Phosphors, Thermographic Screen, Visual Display of Laser Beam

52. Bridges, W. B., P. O. Clark, and A. S. Halstead: High Power Gas Laser Research. Technical Report AFAL-TR-66-369, CFSTI Doc. No. AD807363, January 1967.

Abstract: This report discusses the results of extensive parametric studies and engineering development of carbon dioxide lasers. The design of internal mirror and Brewster window-external mirror lasers is described, as well as experiments involving dc, ac, and rf excitation. The influence of gas additives on laser power and efficiency was investigated for several different diameter discharge tubes. The effect of gas flow rate was observed, and life tests were made with sealed-off lasers. Laser power and efficiency were increased by cooling the discharge tube. The data available from this program and from the literature were combined to investigate the dependence of laser performance on tube diameter.

Three appendices are included. Appendix A is a theoretical analysis of the dependence of the gain coefficient on the translational temperature of the molecules. The possibility of thermal excitation of the lower laser level is evaluated in Appendix B. Appendix C is a bibliography of CO_2 laser publications in the open literature.

Keywords: Theoretical Gain Coefficient, Parameter Study, Efficiency, Thermal Excitation of Lower Laser Level, Single Mode (TEM_{00}), Cavity Configuration, Tube Diameter vs. Optimum Discharge Current, Laser Design, Effects of Axial Magnetic Field, Effect of Molecular Temperature on Gain, Sealed System Lifetime

53. Cheo, P. K. and H. G. Cooper: Gain Characteristics of CO_2 Laser Amplifiers at 10.6 Microns. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 2, February 1967, pp. 79-84.

Abstract: Single-pass gain at 10.6 microns has been studied parametrically in non-flowing CO_2 or buffered CO_2 amplifying media. The gain profile across the amplifier diameter and integrated gain both were determined. Parameters varied included buffer gas type, mixture ratio, gas pressure, amplifier bore, discharge current, and wall temperature. Tube bores of 12, 22, and 34 mm and buffer gases of H_2, He, Ne, Ar, and N_2 were studied. Optimum gain is relatively independent of current density, but decreases with

increasing wall temperature. The pressure-diameter relationship $P_{CO_2} \cdot D \cong 4$ Torr-cm was found to hold for CO_2, CO_2:He, and CO_2:N_2 amplifying media at optimum gain. The gain depends strongly on the CO_2 partial pressure and is relatively insensitive to the buffer gas pressure except for the case of H_2. The maximum gain decreased slowly with increasing amplifier diameter. The highest gain, 1.7 dB/meter, was achieved with a helium buffer gas in amplifiers with a diameter of 22 mm or less. No gain saturation was detected for a 30-dB range of input signal power, from a milliwatt to a few watts. Spectrograms showed that the principal spontaneous emission from CO_2:He amplifiers in the 2000-7000-Å range consisted of CO bands; no CO_2 bands or He line spectra were observed.

Keywords: Amplifier, Additives (H_2, He, Ne, Ar, N_2), Sealed-off System, Gain, Current and Temperature Effects, Pressure and Diameter Dependence

54. Kogelnick, H. and T. J. Bridges: A Nonresonant Multipass CO_2 Laser Amplifier. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 2, February 1967, pp. 95-96.

Abstract: This letter reports that small-signal gains of about 15 dB at a wavelength of 10.6 microns have been obtained with a compact five-pass CO_2-laser amplifier structure. A power output of 5.5 watts was measured at a saturated gain of 7 dB. The laser gas discharge was 1 meter long and was contained in a water-cooled glass tube of 20 mm bore. The tube was terminated by Brewster angle windows of potassium chloride as reported in Bridges and Patel.

Keywords: Nonresonant Multipass Amplifier, Gain

55. Kovacs, M. A., C. K. Rhodes, A. Szöke, and A. Javan: Measurement of Some Molecular Vibrational-Rotational Parameters with an Infrared Heterodyning Technique. Applied Physics Letters, Vol. 10, No. 3, February 1, 1967, pp. 108-110.

Abstract: Frequency mixing of three simultaneously oscillating P-branch laser transitions can be used to obtain accurate spectroscopic information on some of the molecular rotational-vibrational parameters. This has been demonstrated for the 10 micron laser transitions of CO_2 and N_2O.

The present accuracy is limited by the Doppler widths of the infrared molecular transitions. Improved accuracy is possible to within a small fraction of the Doppler width. Furthermore, it is shown that at elevated pressures where pressure broadening is comparable to or exceeds the Doppler width, mode coupling occurs and the laser tends to oscillate on a single axial mode.

Keywords: Spectroscopy, Doppler Line Width, Pressure Broadening, Mode Coupling, Single Axial Mode

56. Sobolev, N. N. and V. V. Sokovikov: Influence of Rate of Disintegration of the Lower Laser Level on the Power of a CO_2 Laser. JETP Letters, Vol. 5, No. 4, February 15, 1967, pp. 99-101.

Abstract: In this paper the authors consider the influence of the relaxation rate of the lower laser level in CO_2 on the magnitude of the inverse population and on the generation power.

Keywords: Relaxation Rates

57. Noldy, R. S. R., J. D. Foster, A. A. Kamila, and A. E. Siegman: Frequency Stabilized Gas Laser, Final Summary Engineering Report. Sylvania Electric Products Inc., Contract No. NAS8-20631, June 18, 1966 - February 17, 1967.

Abstract: To provide long term stabilization, a technique which allows CO_2 laser operation at a wavelength near 10.6 microns to be stabilized with respect to a non-regenerative CO_2 amplifier, was chosen. This technique is analyzed and shown to be capable of providing a frequency stability of about 1 part in 10^{10} using presently available 10-micron detectors. Factors affecting the absolute stability of the CO_2 amplifier frequency are discussed with the conclusion that the pressure variations within the amplifier tube may be the limiting factor for long-term frequency stability. A detailed design is presented for a CO_2 laser system capable of providing greater than 1/2 watt of 10.6 micron radiation, frequency stabilized to within 3 kHz. Techniques for ensuring single-frequency operation in the CO_2 laser without degradation in power output are also discussed.

Keywords: Frequency Stabilization, Non-regenerative Amplifier, Pressure Variations, Single-frequency Operation

58. Polant, R. M. and T. H. Lloyd: Design, Construction, and Study of a Q-Switched CO_2-N_2-He Gas Laser. A.F.I.T. M.S. Thesis, Wright-Patterson Air Force Base, CFSTI Doc. No. AD 651615, March 1967.

Abstract: An electrically driven mechanical Q-switch was placed in a CO_2-N_2-He laser vacuum to eliminate Brewster angle window losses. The resonator length was 179 cm. Laser output was produced at 10.6 microns and 9.6 microns with and without tube cooling. For tube temperatures from 273°K to 183°K, laser output at 4.35 microns was found to vary approximately as exp(constant/$T^{3/2}$). Cooling the laser tube to 77°K changed the system to a CO laser. When Q-switched, it produced laser oscillation on 73 lines in the $\nu \rightarrow \nu$-1 bands of the CO $X^1\Sigma^+$ ground state for $3 \leq \nu \leq 17$. Cascading of these transitions with approximately a 1 microsecond time delay was observed.

Keywords: Spectroscopy, Q-Switching, Cryogenic Cooling of Laser Tube, Additives (N_2, He), Detection

59. Bickart, C. J. and J. N. Fulton: CO_2 Molecular Gas Laser. United States Army Electronics Command, Technical Report ECOM-2818, CFSTI Doc. No. AD-654518, March 1967.

Abstract: The report discusses the experimental results and optimization of a relatively high-power, high-efficiency cw gas laser utilizing a dc excited discharge with a flowing combination of carbon dioxide, helium, and nitrogen as the active laser medium. Continuous laser power output of 126 watts has been measured from a system of 4.7 cm diameter by 2.4 meters long.

Detail of various cavity configurations, reflector materials, power coupling-out methods, and current characteristics of the discharge are discussed. A 90° folded design cavity is described including some intra-cavity Q-switching experiments. These experiments are part of a continuing study of the technology concerning design, construction, and optimization of CO_2 lasers.

Keywords: Cavity Configurations, Intra-cavity Q-Switching, Aperture Coupling, Folded Cavity, Transmission Coupling, Parameter Study, Additive (water vapor)

60. Tang, C. L: Optical Analog of the Transient Nutation Effect. Applied Physics Letters, Vol. 10, No. 5, March 1, 1967, pp. 145-147.

Abstract: The possibility of observing the optical transient nutation effect in CO_2 lasers is considered. A formula for the nutation frequency is derived explicitly for the vibrational-rotational transitions in molecules such as CO_2.

Keywords: Optical Transient Nutation, Nutation Frequency, Line Strength

61. Reynolds, R. S.: Stabilized CO_2 Gas Laser. Sylvania Electronics Systems, First Quarterly Report, Contract No. NAS5-10309, March 1, 1967.

Abstract: This report covers the first quarter of work on the design and fabrication of a 20-watt, frequency-stabilized, single-frequency CO_2 laser. To achieve the 20-watt cw power level and still maintain a required short-term frequency stability of 1 part in 10^{10}, a master oscillator-power amplifier approach has been taken. The present work describes the design of the oscillator cavity and laser tube and also describes the temperature control system and automatic frequency control loop to be used with the laser. Preliminary tests have indicated that it may be possible to achieve the desired short-term frequency stability figure without the need for an external electronic control loop.

Keywords: Frequency Stabilization, AFC Loop, Laser Design, Doppler Line Width

62. Deutsch, T.: Gain and Fluorescence Characteristics of Flowing CO_2 Laser Systems. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 4, April 1967, pp. 151-155.

Abstract: Single-pass gain has been measured for flowing CO_2, CO_2-N_2, CO_2-He, CO_2-N_2-He, and CO_2-N_2-H_2 mixes. The gain for CO_2-N_2 mixes varies as $d^{-0.9}$, where d is the tube diameter. The diameter dependence of the gain is less pronounced for CO_2-N_2-He mixes; a peak gain of 4.7 dB/m was obtained in a 1/2 inch diameter tube. Fluorescence data indicate that the upper laser level population is saturated at 100 mA in all cases. The addition of He, H_2, or O_2 depopulates the lower laser level; helium

further increases the population of the upper laser level. The addition of CO increases the population of the upper laser level, probably by resonant transfer from the excited vibrational states of CO.

Keywords: Gain, Fluorescence, Population of Upper Laser Level, Additives (N_2, He, H_2), Saturation of Upper Laser Level, Depopulation of Lower Laser Level

63. Bridges, T. J. and E. G. Burkhardt: Observation of the Output of a CO_2 Laser by a High-Resolution Thermographic Screen. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 4, April 1967, pp. 168-169.

Abstract: Prompted by a need for a high-resolution thermographic screen to observe mode-patterns from a CO_2 laser the authors modified the screen of McGee and Heilos by mounting the screens onto aluminum blocks which act as heat sinks. The flow of heat is almost entirely normal to the film, resulting in much improved resolution and time constants at the expense of sensitivity.

Keywords: Thermographic Screen, Viewing CO_2 Laser Mode Patterns

64. Zernike, F.: Far Infrared Generator. Final Report, Perkin-Elmer Corp., Contract No. Nonr-4680 (00), CFSTI Doc. No. AD-652830, April 30, 1967.

Abstract: A description is given of studies aimed at producing a far infrared generator by mixing two laser generated frequencies. Attempts to use two CO_2 cw operating lasers proved unsatisfactory. A successful experiment was performed, however, by using a single Q-switched CO_2 laser simultaneously radiating at 9.6 and 10.6 microns and focused on an InSb crystal.

Keywords: InSb Detector, Q-Switching, Far-Infrared Generation, 9.6 micron Radiation

65. Jacobs, G. B. and H. C. Bowers: Extension of CO_2-Laser Wavelength Range with Isotopes. Journal of Applied Physics, Vol. 38, No. 6, May, 1967, pp. 2692-2693.

Abstract: This paper reports tunable laser emission in both the 00°1-10°0 and 00°1-02°0 bands of $^{13}C^{16}O_2$, and in particular in a mixture of the two isotopes, $^{12}C^{16}O_2$ and $^{13}C^{16}O_2$.

Keywords: Isotope Laser, Tunable Lasing, Spectroscopy

66. Freed, C.: Stability Measurements of CO_2-N_2-He Lasers at 10.6 Micron Wavelength. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 5, May 1967, pp. 203-205.

Abstract: The short term stability of the beat frequency of two stable, single-frequency (TEM_{00q} mode) CO_2-N_2-He lasers has been measured. Both lasers were sealed-off and free running without any feedback stabilization. The width of the spurious frequency modulation was typically on the order of 9 kHz and 20 kHz for observation times of 3×10^{-2} and 1 second, respectively. On one occasion, the frequency spread remained less than the spectrum analyzer resolution (approximately 500 Hz) for several seconds, and the slow drift did not exceed a few kilohertz for several minutes. The observed frequency jitter was caused by environmental fluctuations such as acoustic vibrations, plasma instabilities, power supply noise, variations of temperature and pressure, etc. Therefore, these measurements should not be confused with the ultimate spectral width of a laser oscillator; this line width is dominated by frequency fluctuations caused by the random walk of the oscillation phase under the influence of spontaneous emission or quantum noise.

Keywords: Stability Measurements, Beat Frequency, Optical Mixing, Sealed-off System, Spurious Frequency Modulation, Spectral Line Width

67. Whitehouse, D. R.: High Power Gas Laser Research. Final Technical Report, CFSTI Doc. No. AD 653031, May 1967.

Abstract: This report concerns the investigation and optimization of high power and high efficiency in the cw gas laser utilizing carbon dioxide, nitrogen, and helium as the active laser medium. In all cases, the gases are excited by an electrical discharge. With the gases flowing through the tube, we have attained a continuous power output of 1200 watts at an efficiency of 17 percent in a 20-meter tube, and a linear

power density of 80 watts per meter of discharge length in a 3-meter tube. With a fixed volume of gas in a sealed-off tube, the maximum linear power density is 28 watts per meter at an efficiency of 7 percent.

In the area of flowing gas lasers, we have made an experimental investigation into the unsaturated gain characteristics at 10.6 microns and their dependence on tube diameter, gas mixing, and flow speed. The measurements were taken with a laser bridge constructed in our laboratory, which was of sufficient resolution to measure the radial profiles of the gain. For the high-power oscillators, we have determined the dependence of the power on tube length, gas pressure, pumping speed, output coupling, and mode control. For sealed-off lasers, we have determined the dependence of the output power on the gas mix, pressure, and tube preparation. Some results on the initial phases of long life tests are also included.

Much of the data which has been accumulated indicates that the present limitations of output power in large bore tubes and sealed-off tubes stem from the heating of the gas by the discharge. This is corroborated by theoretical calculations of the heat transfer and temperature profile in the tube.

Keywords: Thermal Effects, Unsaturated Gain, Sealed-off System, Parameter Study

68. Crane, R. A. and A. L. Waksberg: Visible Side-Light Emission Properties of a CO_2-N_2-He Plasma Induced by the CO_2 Laser Radiation Field. Applied Physics Letters, Vol. 10, No. 9, May 1, 1967, pp. 237-239.

Abstract: The effect of laser action, in CO_2 laser plasmas, on the spontaneous emission in the visible spectral region is studied by means of a phase-lock technique. The results reveal that direct collisions between molecules in the primary laser cycle and highly excited states have an important influence on the properties of the plasma.

Keywords: Plasma Properties, Side-Light Emission Properties, Collision Effects, Phase-Lock Technique

69. Miles, P. A. and F. A. Horrigan: Research Study of a CO_2 Laser Radar Transmitter. Semiannual Technical Summary Report, Raytheon Research Division, June, 1967.

Abstract: This report concerns the investigation of physical properties of laser amplifiers, using electrically excited mixtures of CO_2, N_2, and He with a view of producing high-power pulse emission with well-controlled temporal and spatial form. The object of this investigation is to design and build such a source with an average power of 1 kW in a form suitable for use as a laser radar transmitter. Designs have been developed for both dc- and pulse-excited amplifiers and the physical quantities of importance in these designs have been measured. The most notable of these are: the signal intensity required to drive an amplifier to saturation, information on the refractive properties of the discharge, the time constant determining maximum pulse repetition rates, both for the input pulse trace and for the pulse excitation process, and the practical gain level that can lead to self-oscillation in the amplifier. These measurements lead to the choice of a system in which a train of 10-15 microsecond pulses at a repetition rate of 10 - 12 kHz is amplified by a 50 meter length of dc-excited power amplifier.

Keywords: Amplifier, Laser Radar, Superradiance Effects, Gain, Optical Materials, Spectral Line Width, Doppler Line Width

70. Witteman, W. J.: A Sealed-Off Michelson Type CO_2 Laser for Diagnostic Studies of Gaseous Plasmas. Applied Physics Letters, Vol. 10, No. 12, June 15, 1967, pp. 347-349.

Abstract: An experimental arrangement of a Michelson type CO_2 laser for plasma diagnostic studies of ac discharges is described. The principle of the apparatus is based on the phenomena of strong competition between the rotational transitions. If a phase shift is caused by the plasma to be studied, the intensity distribution of the lasing transition is changed. The system has been used successfully for measuring (with a wavelength of 10.6 microns) changes in refractive index on the order of 10^{-9}.

Keywords: Plasma Diagnostics, Michelson-Type CO_2 Laser, Line Competition, AC Discharges

71. Wieder, I.: Flame Pumping and Infrared Maser Action in CO_2. Physics Letters, Vol. 24A, No. 13, June 19, 1967, pp. 759-760.

Abstract: Continuous infrared maser action has been observed in CO_2 excited by purely chemical means. The methods employed, which we call chemi-optical resonant pumping, utilizes resonance radiation from molecules formed by combustion to excite other molecules isolated from the reaction.

Keywords: Chemi-Optical Resonant Pumping, Resonance Radiation, Doppler Broadening, Line Width, Flame Pumping

72. Bridges, T. J. and A. R. Strnad: Rapid Scan Spectrometer for CO_2 Laser Studies. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 7, July 1967, pp. 335-337.

Abstract: The problem of studying the strong competition between the lines of oscillation in molecular gas lasers has been solved by modifying an 836 Perkin Elmer spectrometer to give a repetitive rapid scan of about 1 percent of its operating wavelength.

Keywords: Line Competition, Repetitive Scan Spectrometer

73. Carswell, A. I. and J. I. Wood: Plasma Properties of a CO_2 Laser Discharge. Journal of Applied Physics, Vol. 38, No. 7, July 1967, pp. 3028-3030.

Abstract: This note describes measurements in which electrical probes, microwaves, and optical tenchiques have been used to examine the plasma parameters of the electrical discharge in a carbon dioxide laser and to investigate the changes in these parameters brought about by interrupting the lasing action in the cavity.

Keywords: Plasma Properties of CO_2 Laser, Physical Structure of Laser, Discharge Impedance

74. Whitehouse, D. R: Understanding CO_2 Lasers. Microwaves, Vol. 6, No. 7, July 1967, pp. A6-A14.

Abstract: A detailed treatment is given of a laser system that holds great promise for high-power applications. Included are design procedures and parameter trade-off considerations.

Keywords: Discharge Properties, Output Spectrum, Design Procedures, Parameter Study

75. Roberts, T. G., G. J. Hutcheson, J. J. Ehrlich and W. L. Hales: Experimental Development of N_2-CO_2 Lasers. Army Missile Command, Plasma Physics Branch, Report No. PR-TR-67-11, CFSTI Doc. No. AD 659767, July, 1967.

Abstract: Recent techniques investigated in the Army Missile Command N_2-He-CO_2 laser program have produced several lasers with output powers in excess of 100 W/m and efficiencies greater than 25 percent. Scaling laws various discharge configurations, gas mixtures, optical components, and spectra of the output radiation and of the discharges were studied in attempts to determine the optimum operating characteristics and to produce a better understanding of the mechanisms which make these molecular lasers so efficient. This information was used to design and construct an N_2-He-CO_2 laser 180 ft. long, which operates in the multi-kilowatt range with efficiencies and powers per unit length comparable to smaller lasers of similar construction. This laser was constructed in modular form, each module being approximately 10 ft. long. The design and operation characteristics of these lasers are discussed and the performance data obtained as a function of length each time a module was added are presented.

Keywords: Physical Structure of Laser, Additives (Ar, He, Dz, Ne, air, O_2, NO), Aperture Coupling, Multikilowatt Power Output, Tube Wall Cooling, Parameter Study

76. Cheo, P. K: Relaxation of the 10.6 Micron CO_2 Laser Levels by Collisions with H_2. Applied Physics Letters, Vol. 11, No. 2, July 15, 1967, pp. 38-40.

Abstract: Time characteristics of the afterglow gain of a pulsed CO_2:H_2 laser amplifier were investigated. Evidence shows that a rapid nonradiative transfer of population from the upper to the lower CO_2 laser levels occurs at higher H_2 pressures (P greater than 2 Torr). An absorption pulse on the order of 1 msec in duration following the initial gain period is attributed to population accumulation (or a bottleneck) at the 01°1 level.

Keywords: Afterglow Gain, Pulsed Amplifier, Population Accumulation, Relaxation Collisions with H_2, Upper Laser Level Depletion

77. Hotz, D. F. and J. W. Austin: Gain Saturation Flux and Stimulated Emission Cross Section for the 10.6 Micron Line of CO_2. Applied Physics Letters, Vol. 11, No. 2, July 15, 1967, pp. 60-62

Abstract: Gain saturation for the 10.6 micron transition of CO_2 has been measured in a single-pass configuration and the saturation flux found to be (22 ± 2) W/cm^2. Knowledge of the saturation flux and the inversion production rate provides an estimate of 3×10^{-18} cm^2 for the stimulated emission cross section of the transition.

Keywords: Gain Saturation, Inversion Production Rate, Saturation Flux

Note: Text correction appear in Applied Physics Letters, Vol. 11, No. 4, August 15, 1967, pp. 141-142.

78. Peacock, G. R., W. P. Hansen, and S. Fine: Increasing the Power Output from Inexpensive CO_2 Lasers. American Journal of Physics, Vol. 35, No. 8, August 1967, pp. 176-177.

Abstract: Inexpensive CO_2 molecular gas lasers have been constructed. This report describes a method for increasing power output from these devices by using a simple technique for lengthening the active gas tube and by introducing a cooling system. A novel combination Brewster-angle window holder which also serves as an electrode is described.

Keywords: Inexpensive CO_2 Laser, Physical Structure of CO_2 Laser, Hazards

79. Meneely, C. T.: Laser Mirror Transmissivity Optimization in High Power Optical Cavities. Applied Optics, Vol. 6, No. 8, August, 1967, pp. 1434-1436.

Abstract: One of the problems encountered in building Fabry-Perot cavities for laser use is that of optimum output coupling through the choice of appropriate output mirror reflection coefficients. This problem has been particularly acute in CO_2 laser systems where the unusually high gain involved indicates that a wide range of reflectivities may be necessary for optimum coupling.

The optimization problem lies in the fact that the gain of a lasing line $G(\omega)$ is a function of the radiation energy density in the laser cavity ω, which is in turn affected by the output coupling due to the mirror transmissivities. This problem may be solved if one knows the approximate form of $G(\omega)$. In this paper the authors assume that $G(\omega)$ is closely approximated by Rigrod's expression, $G(\omega) = G_o/(1 + \frac{\omega}{\omega_o})$ where G_o is the gain at threshold and ω_o is some saturation parameter.

Keywords: Mirror Reflectance Optimization, Gain, Constant Internal Loss, Radiation Energy Density in Cavity, Mirror Coating Damage

80. Cheo, P. K.: Effects of CO_2, He, and N_2 on the Lifetimes of the 00°1 and 10°0 CO_2 Laser Levels and on Pulsed Gain at 10.6 Microns. Journal of Applied Physics, Vol. 38, No. 9, August, 1967, pp. 3563-3568.

Abstract: Relaxation times of the 00°1 and 10°0 CO_2 vibrational levels and the afterglow gain at 10.6 microns were studied by a pulsed gain technique, for pure CO_2, CO_2:He, and CO_2:N_2 gas mixtures in 22-mm- and 34-mm-bore nonflowing laser amplifiers. Measurements of the exponential rise, τ_r, and decay, τ_d, times of the afterglow gain pulse were made using a cw 10.6-micron CO_2 laser as the amplifier input radiation source. Evidence is presented to support the interpretation of τ_r and τ_d as measures of the effective lifetimes of the 10°0 and 00°1 CO_2 laser levels, respectively. For the case of a pure CO_2 gas in the pressure range from 1 to 8 Torr, the measured τ_r and τ_d values vary from 50 to 250 microseconds and 0.3 to 2.5 milliseconds, respectively. The reciprocals of each increase almost linearly with increasing CO_2 pressure for P greater than 4 Torr. Collision cross section for volume quenching in pure CO_2 are computed to be $\sigma_{00°1} = 2.86 \times 10^{-19}$ cm^2 and $\sigma_{10°0} = 1.62 \times 10^{-18}$ cm^2, assuming $T_{gas} = 300°K$. Addition of helium to CO_2 causes essentially no change to $\tau_{00°1}$ but results in a substantial decrease in $\tau_{10°0}$. The measured collision cross section for quenching of the 10°0 level population by He is $(\sigma_{10°0})_{He} = 1.04 \times 10^{-18}$ cm^2, about two-thirds of that obtained for CO_2-CO_2 collisions. Nitrogen, on the other hand, causes an increase in both $\tau_{00°1}$ and $\tau_{10°0}$ by as much as a factor of two at P greater than 5 Torr.

The peak values of amplifier gain in the afterglow, G_p, are higher and depend more critically on tube bore than those obtained for cw discharges. The relative values of optimum G_p for CO_2, CO_2:He, and CO_2:N_2 are consistent with those obtained from cw gain measurements.

Keywords: Afterglow Gain, Afterglow Rise and Decay Times, Amplifier Gain, Relaxation Time, Lifetime of Upper and Lower Laser States, Additives (N_2, He)

81. Basov, N. G., A. N. Ordevskii, and V. A. Shcheglov: Thermal Methods for Laser Excitation. Soviet Physics - Technical Physics, Vol. 12, No. 2, August, 1967, pp. 243-249.

Abstract: Methods of rapid cooling of gaseous systems for the purpose of obtaining states with population inversion are discussed. A number of actual gaseous systems are pointed out which are suitable for the production of inversion by means of thermal pumping. There is a discussion of the possibility of producing a laser in the infrared region by using a molecular beam.

Keywords: Thermal Laser Excitation, Adiabatic Cooling of Gaseous Systems, Shock Tube, Nozzle Cooling

82. Wood, O. R. and S. E. Schwarz: Passive Q-Switching of a CO_2 Laser. Applied Physics Letters, Vol. 11, No. 3, August 1, 1967, pp. 88-89.

Abstract: Passive Q-switching of a CO_2-N_2-He laser has been obtained, using SF_6 gas as the saturable absorber. Peak power is 1 kW, in what appears to be a single transverse mode. This is 200 times the cw level for the same configuration and one-fifth that obtained with a mechanical Q-switch. Pulse rates are in the range 10^3 to 10^4 pulses per second. Operation is on a single vibrational-rotational line, unlike the case of cw operation.

Keywords: Q-Switching (Passive), SF_6 Absorption Cell, Pulse Rates, Additive (He)

83. Sviridov, A. G., N. N. Sobolev, and G. G. Tselikov: Plasma Gas Temperatures in the Discharges Used for CO_2 Lasers. JETP Letters, Vol. 6, No. 3, August 1, 1967, pp. 62-65.

Abstract: This paper is devoted to the results of an investigation of the dependence of laser tube wall temperature on different parameters of the discharges used for CO_2 lasers. The experiments were made with a continuous flow of the gas mixture of rates up to 1 m/sec. The wall temperature was measured by determining the relative intensity of the rotational lines of the (O,O) bands of the second positive system of N_2 (edge of band $\lambda = 3371$ Å).

Keywords: Laser Tube Wall Temperature, Plasma Properties of CO_2 Laser Discharge

84. Dezenberg, G. J. and J. A. Merritt: The Use of a Multipath Cell as a CO_2-N_2 Gas Laser Amplifier and Oscillator. Applied Optics, Vol 6, No. 9, September 1967, pp. 1541-1543.

Abstract: A multipath cell using a modified White mirror system has been operated as an amplifier and as an oscillator at the 10.6 micron CO_2 transition of the CO_2-N_2 gas laser. An oscillator tube efficiency of 33% and an amplifier power gain of 8.7 have been obtained. With a specific gas mixture, the amplifier saturated output power is approximately one-half that of the maximum oscillator output.

Keywords: Amplifier, Multipath Cell

85. Inaba, H., T. Kobayashi, K. Yamawaki, and A. Sugiyama: Direct Observation of Output Beam Patterns from N_2-CO_2 Laser at 10.6 Microns by Thermal Development Method. Infrared Physics, Vol. 7, No. 3, September 1967, pp. 145-149.

Abstract: A thermal development method is presented for observing and recording directly the output pattern of laser oscillations at 10.6 microns from N_2-CO_2 systems. This method utilizes the commercially available Kalver film in which the development is produced by the infrared laser beam, following uniform exposure to the near ultraviolet light around 0.4 microns. It was proved experimentally that the Kalver image obtained with this procedure gives favorable results with continuous tone characteristics as compared with the evaporographic method for detecting the infrared radiation from relatively low temperature sources. Some typical examples of the direct oscillation pattern from the

N_2-CO_2 laser system, using the external resonator configuration and having a central hole in one of the mirrors for the output power coupling are shown. The effect of the window employed for the discharge tube on the performance of laser operation is also discussed.

Keywords: Kalver Film, Visual Beam Pattern Observation, Hole Coupling

86. Carbone, R. J.: Long-Term Operation of a Sealed CO_2 Laser. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 9, September 1967, pp. 373-375.

Abstract: The life expectancy of a sealed CO_2 laser depends, to a great extent, on the interaction of the molecules existing in the discharge at the cathode. The data reported here indicates that after operation of a sealed laser, only CO and O_2 are formed in concentrations comparable to the initial fill gases of CO_2, N_2, and He. The CO, CO_2, and O_2, in particular, were found to be completely adsorbed at the Ni cathode within several hundred hours of tube operation. A loss of 10.6 micron power output accompanied this adsorption. As expected, the process was reversible to a degree since the laser resumed operation at the initial power level after the cathode region has been heated to 300°C. This process of adsorption-desorption was repeated several times up to an accumulated operating time of 705 hours. During this time, the power output remained at a substantially constant value. However, the loss of CO_2 by carbon deposits ultimately means an end to tube life.

Keywords: Life Expectancy of Sealed-off System, Carbon Deposits, Cathode Interaction, Cathod Rejuvenation, Adsorption, Desorption

87. Makhov, G. and I. Wieder: Vibrational Excitation of CO_2 by Transfer from Thermally Excited Nitrogen. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 9, September 1967, p. 378.

Abstract: Fluorescence from CO_2 molecules excited by transfer from heated nitrogen has been observed. Insofar as thermal excitation of nitrogen can be accomplished by chemical means, this process may be utilized to implement a chemically excited laser.

Keywords: Fluorescence, Chemically-Excited Laser, Thermal Excitation of Nitrogen

88. Reynolds, R. S.: Stabilized CO_2 Gas Laser. Quarterly Report, Sylvania Electric Products, Western Division, Contract No. NAS5-10309, September 1, 1967.

Abstract: Testing and construction continued toward the development of a sealed-off, 20-watt, stabilized single-frequency CO_2 laser. Stability measurements on a 3-watt single-mode laser oscillator have shown frequency stabilities as high as 2 parts in 10^{10} (6 kHz) over 100 msec periods and 3 parts in 10^8 (1 MHz) over 30-minute periods. The design of a dc amplifier for use with the oscillator is presented which should provide about 10 dB of power gain. The design is also presented for the electrical console which will house the 20-watt laser power supplies and cooling system.

Keywords: Frequency Stabilization, Single Frequency Operation, Laser Design, Laser Amplifier, Single-mode Operation, Sealed-off System

89. Taylor, F. M., A. Lombardo, and W. C. Eppers: Effect of a Heated Platinum Wire on a Sealed CO_2 Laser System, Applied Physics Letters, Vol. 11, No. 9, September 15, 1967, pp. 180-182.

Abstract: A heated platinum wire was used in a sealed CO_2-N_2-He laser system, resulting in increases in output power that were dependent on the initial fill pressure of CO_2. The system was also filled with a CO_2-He mixture and made to lase. Heating of the platinum wire caused a decrease in output power. It was tentatively concluded that the platinum catalyzes the reaction $CO + O \rightarrow CO_2$, permitting a higher concentration of CO_2 in a sealed system than is otherwise possible.

Keywords: Sealed-off System, Heated Platinum Wire

90. Horrigan, F. A., C. A. Klein, R. I. Rudko, and D. T. Wilson: High-Power Gas Laser Research. First Quarterly Technical Report, Raytheon Research Division, Contract No. DA-AH01-67-C-1589, September 30, 1967.

Abstract: This report presents a brief description of a multi-kilowatt CO_2 laser, a preliminary survey of various (semiconducting) materials of potential use as 10.6 micron windows, proposed experimental techniques for measuring absorption coefficient at 10.6 microns, and an analytic model for catastrophic thermal runaway in semiconducting windows.

Keywords: Multi-Kilowatt CO_2 Laser, Semiconductor Laser Windows, Thermal Runaway in Semiconductor Laser Windows

91. Tychinskii, V. P.: Powerful Gas Lasers. Soviet Physics - Uspekhi, Vol. 10, No. 2, September - October 1967, pp. 131-152.

Abstract: This is a review article on CO_2 lasers.

Keywords: Lifetimes of Vibrational Levels, Discharge Characteristics, Competition of Transitions, Gain in Molecular Systems, Inversion Mechanism, Temperature Effects, Energy Relations

92. Sobolev, N. N. and V. V. Sokovikov: CO_2 Lasers. Soviet Physics - Uspekhi, Vol. 10, No. 2, September - October 1967, pp. 153-170.

Abstract: This is a review article on CO_2 lasers.

Keywords: Laser Construction, Pulsed Laser, Q-Switching Technique, Wavelength Tabulation, Selective Excitation, Electronic Excitation, Population Inversion, Additive (H_2O), Spectroscopy, Doppler Line Width

93. Witteman, W. J.: Sealed-off High-Power CO_2 Lasers. Philips Technical Review, Vol. 28, No. 10, October 1967, pp. 287-296.

Abstract: This is a review article on sealed-off CO_2 lasers.

Keywords: Sealed-off System, Additives (H_2O, N_2), Inversion Mechanism, Variable Coupling

94. Fantasia, J.: An Analytical and Experimental Investigation of Limited Operational Life of CO_2 Lasers to Achieve a Non-Flowing Sealed CO_2 Gas Laser. Final Report, NASA Contractor Report No. 12-590, CFSTI Doc. No. N68-13277, October 1967.

Abstract: Dissociation of pure carbon dioxide in a gas discharge, the effects of water vapor and xenon upon dissociation, and the influence of electrode material on clean-up rate were investigated in connection with the study to develop a sealed-off CO_2 gas laser. The dominant CO_2 depeletion mechanisms were found to be initially from dissociation, followed by a steady clean-up of the dissociation products and the CO_2 by the electrodes. Dissociation rate is strongly dependent on additive gases and indirectly dependent on the clean-up rate for a given electrode material. A combination of nickel electrodes and carbon dioxide with water vapor added produced a very stable CO_2:CO:O_2 concentration. A system employing this combination would be expected to run for several hundred hours before total depeletion of the CO_2 occurs.

Keywords: Frequency Stabilization, Additives (Xe, H_2O), CO_2 Dissociation, Sealed-off System, Electrode Materials, Gas Clean-up

95. McElroy, J. H. and H. E. Walker: Aperture Coupling of a Carbon Dioxide Laser Employing a Near-Confocal Optical Resonator. Goddard Space Flight Center, Greenbelt, Maryland, NASA TM X-524-67-513, October 1967.

Abstract: Materials difficulties encountered at the 10.6 micron wavelength of the CO_2 laser often dictate that the laser output be obtained by aperture coupling through a hole in the laser output mirror. This document presents the results of measurements made on an aperture-coupled carbon dioxide laser using a near-confocal optical resonator. The effects of the coupling hole diameter and mirror spacing are related to laser multimode power output and mode structure. It is found that odd-symmetric modes dominate and, if a simple mode structure is required, with maximum axial power density, the diameter of the output coupling hole must be restricted.

Keywords: Aperture (Hole) Coupling, Near-Confocal Optical Resonator, Mode Structure, Intra-cavity Iris

96. Hotz, D. F. and J. W. Austin: Saturation Flux and Stimulated Emission Cross Section of the CO_2 Laser. Research and Development Report, Navy Electronics Lab., Center for Command, Control, and Communications, CFSTI Doc. No. AD 663270, October 11, 1967.

Abstract: Development of a high radiance laser source is a necessary preliminary to study of nonlinear phenomena in the gases of a typical atmosphere. Before an efficient laser power amplifier can be designed, two gain limiting effects must be understood: gain saturation and hole burning. Gain saturation flux and stimulated emission cross section for the strong laser transition in CO_2 were measured. The saturation flux was found to be $22 \pm 2\ W/cm^2$ for steady state emission. The cross section was found to agree with theory only after correction for participation of appreciable numbers of rotational levels in the gain process. It was concluded that gain line width is homogeneously saturable for typical CO_2:N_2:He mixtures in which pressure exceeds 10 torr, and that hole burning will not occur until cw flux levels of the order of 100 000 w/cm^2 are achieved. Hole burning will appear at about 10 000 W/cm^2 for Q-pulsed amplification.

Keywords: Saturation Flux, Amplification, Gain Saturation, Spectral Hole Burning, Gain Line Width

97. Mocker, H. W.: 10.6 Micron Optical Heterodyne Communication System. Phase 3 Report on Contract No. NAS8-20645, October 31, 1967.

Abstract: This report describes the effort made towards the design and construction of a 10.6 micron optical heterodyne communication system during the reporting period from August 1 to October 31, 1967.

Keywords: Communications System, Heterodyne Detection, Frequency Stabilization, AFC Loop, Piezoelectric Frequency Control, Piezoelectric Modulation

98. Roberts, T. G., G. J. Hutcheson, J. J. Ehrlich, W. L. Hales, and T. A. Barr, Jr.: High-Power N_2-CO_2-He Laser Development. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 11, November 1967, pp. 605-609.

Abstract: Several lasers with output powers ranging from 40 to over 100 W/m and efficiencies greater than 25 percent have been produced at Redstone Arsenal. The information obtained from these lasers has been used to design and construct a 180-foot-long N_2-CO_2-He laser which operates in the multikilowatt range with efficiencies and powers per unit length comparable to the smaller lasers of similar construction. The laser has been constructed in modular form. Each module is 9 feet, 8 inches long, and performance data were obtained as a function of length each time modules were added. The design and operating characteristics of these lasers are discussed, and also, the data which were obtained as a function of length are presented.

Keywords: Multikilowatt CO_2 Laser, Modular Construction, Additives (He, air, N_2, Ne, Ar)

99. Lee, P. H. and M. L. Skolnick: Interferometric Methods for Measuring Dispersion in CO_2 Laser Oscillations and Amplifiers. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 11, November 1967, pp. 609-612.

Abstract: An interferometric method is described for measuring the phase shifts caused by anomalous dispersion in laser active media under actual oscillating conditions. In addition, some data are presented which show how this method can be used to measure dispersion in a single-frequency 10.6-micron CO_2 laser plasma.

The application of an interferometer of this kind to laser frequency stabilization is also discussed, and an absolute frequency stabilization scheme for CO_2 lasers is suggested. Because the phase shift observed is an anti-symmetrical function about the center of the molecular resonance, it can be used directly as an absolute frequency control discriminant. The resulting frequency control system requires neither amplitude nor frequency modulation of the laser.

A modification of a Mach-Zehnder interferometer for the measurement of dispersion in laser amplifiers is also described. This modified interferometer was used to measure phase shift as a function of frequency in an unsaturated traveling-wave CO_2 amplifier. The oscillographic data resulting from these measurements are shown.

Keywords: Frequency Stabilization, Dispersion, Amplification, Interferometric Frequency Control, Mach-Zehnder Interferometer

100. McCubbin, Jr., T. K. and Y. H. Hahn: Infrared Emission of CO_2-N_2 and CO_2-N_2-He Plasmas. Journal of the Optical Society of America, Vol. 57, No. 11, November 1967, pp. 1373-1375.

Abstract: A high-resolution spectroscopic study has been made of the emission in the 4.3 micron region of electrically excited CO_2-N_2 and CO_2-N_2-He plasmas. CO_2-rich plasmas emit an intense spectrum in which P-branch and low-J R-branch lines appear in absorption. The R-branch band heads ($J \cong 120$) appear as emission features in such spectra and there is a region of mixed absorption and emission. CO_2-N_2 plasmas which would sustain laser oscillations in a suitable cavity exhibit emission lines and derive most of their intensity from the fundamental and four hot bands of the naturally abundant CO_2 isotope. With the mixture ratio and pressure carefully adjusted, the CO_2-N_2-He plasma emits lines of the 00°3-00°2 and 00°2-00°1 bands. Bands from $^{13}C^{16}O_2$, $^{12}C^{16}O^{18}O$, and $^{13}C^{16}O^{18}O$, which are prominent in the CO_2 absorption spectra, do not appear in the plasma spectra. The molecular constants ω_3°, x_{33}°, and y_{333} are derived from bands in the $00\nu_3 - 00(\nu_3 - 1)$ sequence.

Keywords: Spectroscopy, Isotopes, Spectral Lines

101. Paananen, R. A.: A CO_2-N_2-He-Xe Laser. Proceedings of the IEEE, Vol. 55, No. 11, November 1967, p. 2035.

Abstract: The operating efficiency of the CO_2-N_2-He 10.6-micron laser has been increased by 12-25 percent through the addition of Xe gas to the existing ternary flowing gas mixture. The efficiency increase comes about through a reduction in the laser discharge voltage, leaving the output power essentially unchanged.

Keywords: Additive (Xe)

102. Sharma, R. D. and C. A. Brau: Near-Resonant Vibrational Energy Transfer in N_2-CO_2 Mixtures. Physical Review Letters, Vol. 19, No. 22, November 27, 1967, pp. 1273-1275.

Abstract: Recent experiments indicate that the N_2-CO_2 near-resonant vibration-transfer cross section has a strong negative temperature dependence for temperatures below about 1000°K, in contrast to the behavior predicted by the theory of Schwartz, Slawsky, and Herzfeld. It is shown that this anomalous behavior is due to the long-range dipole-quadrupole interaction between the molecules.

Keywords: Dipole-Quadrupole Interaction, Near-resonant Vibrational Transfer Cross Section

103. Cheo. P. K.: Effects of Gas Flow on Gain of 10.6 Micron CO_2 Laser Amplifiers. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 12, December 1967, pp. 683-689.

Abstract: Small-signal gain of flowing gas CO_2 laser amplifiers at 10.6 microns has been optimized for media including pure CO_2, CO_2:N_2, CO_2:He, CO_2:CO, CO_2:O_2, CO_2:N_2:He, CO_2:CO:He, and CO_2:N_2:CO. Optimum gain of all flowing gas systems studied increases monotonically with increasing gas flow rate. In the low CO_2 flow rate region, $10 < R_{CO_2} < 50$ cm^3/min, gas flow enhances the gain most for systems containing N_2. Results provide strong evidence that the rapid increase in gain with flow rate in CO_2:N_2 mixtures is due to removal by convection of the dissociated product CO. For $50 < R_{CO_2} < 200$ cm^3/min, a slow linear increase in gain of all gas mixtures with increasing flow rate occurs and is attributed to the cooling of gas temperature by convection. A stronger dependence of gain G on amplifier bore D, viz. G proportional to 1/D, was obtained for flowing gas media relative to that previously observed for nonflowing gas mixtures which is consistent with the proposed mechanism of gas cooling by convection. Highest gain values obtained were 7.8 and 6.2 dB/m with the flowing gas mixtures CO_2:N_2:He and CO_2:CO:He, respectively, in a 12 mm bore water-cooled amplifier tube. Similarities between CO_2:N_2 and CO_2:CO systems suggest that pumping of the CO_2 laser by resonant transfer from $CO^*(\nu = 1)$ can be significant.

Keywords: Gain, Flow Rate Dependence of Gain, CO_2 Dissociation

104. Witteman, W. J.: High-Output Powers and Long Lifetimes of Sealed-Off CO_2 Lasers. Applied Physics Letters, Vol. 11, No. 11, December 1, 1967, pp. 337-338.

Abstract: Output powers up to 63 W/m and lifetimes in excess of 1000 hr are obtained with sealed-off CO_2 lasers. The addition of 0.2 Torr H_2O or 0.2 Torr H_2 to the conventional mixture of CO_2, N_2, and He is essential to obtaining these results. The influence of the observed OH radicals on the extended lifetime is discussed.

Keywords: Sealed-off System, Additives (H_2O, H_2), OH Radicals, Long Lifetime

105. Javan, A., M. A. Kovacs, M. J. Kelly, and C. K. Rhodes: Semi-annual Technical Summary Report, No. 1, Massachusetts Institute of Technology, Contract N00014-67-A-0204-0014, ARPA Order 306, Project Defender, CFSTI Doc. No. AD 665694, December 31, 1967.

Abstract: The diffusion coefficient for the 001 state of CO_2 into CO_2 is measured and is shown to be twice larger than the self-diffusion coefficient of CO_2. The wall deexcitation rate of the 001 state is also determined in detail. In another experiment, the collision lifetime of the 100 state, the lower laser level, is measured for the first time and studied in detail. A theoretical calculation is completed dealing with details of a CO_2 amplifier and the manifestation of the Lamb dip effect.

Keywords: Collision Lifetime of CO_2 100 State, CO_2 Amplifier Saturation, Lamb Dip Effect, Diffusion Coefficient for CO_2 001 State, Wall Deexcitation of CO_2 001 State

106. Spinak, S., P. P. Barron, S. Karp, R. B. Hankin, and R. H. Meier: Observations of CO_2 Laser Radiation with an Infrared Image Converter. Applied Optics, Vol. 7, No. 1, January 1968, pp. 17-19.

Abstract: Visual observation of complex diffraction, interference, and mode distributions of a CO_2 laser, operating at 10.6 microns, was accomplished using an ir image converter. Spatial resolution of better than 75 microns was obtained with a dynamic range of at least 30:1.

Keywords: IR Image Converter, Visual Observation of CO_2 Laser Beam

107. Condas, G. A.: Use of Hydrated Salts as Visual CO_2 Laser Thermographic Screen. IEEE Journal of Quantum Electronics, Vol. 4, No. 1, January 1968, pp. 40-41.

Abstract: In this paper Condas reports the use of hydrated salts as visual CO_2 laser thermographic screens. Unlike the screens of McGee and Heilos, and the subsequently improved version of Bridges and Burkhardt, Condas' hydrated salt screens require no ultraviolet illumination. The darkened surroundings required to use Radelin papers is also obviated.

Keywords: Thermographic Screens, Visual Observation of CO_2 Laser Beam, Hydrated Salt Screen

108. Mocker, H. W.: Pressure and Current Dependent Shifts in the Frequency of Oscillation of the CO_2 Laser. Applied Physics Letters, Vol. 12, No. 1, January 1, 1968, pp. 20-23.

Abstract: The shift of the frequency of oscillation of the 00°1-10°0 rotation-vibration band at 10.6 microns of a CO_2 laser has been investigated as a function of total pressure, CO_2 partial pressure, discharge current, and cavity mode position. The measurements were made by heterodyning two passively stabilized CO_2 lasers, both oscillating in a single transverse mode and a single frequency at the P branch of the 00°1-10°0 rotation-vibration band of CO_2. The result yielded a 5-8 MHz/Torr frequency shift toward red due to an increase in total pressure and a 500-900 kHz/mA shift toward blue due to an increase in excitation. The amount of frequency shift due to excitation was found to be independent of the location of the cavity resonance with respect to Doppler center. The dependence on CO_2 partial pressure was also determined.

Keywords: Laser Frequency Shift due to Pressure Variations, Laser Frequency Shift due to Excitation Variations, Spectroscopy, Heterodyne Detection, Doppler Center

109. Reynolds, R. S.: Final Report on Stabilized CO_2 Gas Laser, Sylvania Electronic Systems, Western Division, Mountain View, California, Contract No. NAS5-10309, January 30, 1968.

Abstract: This report describes the results of a program directed toward the design and development of a CO_2 laser capable of high power at a single frequency, highly stabilized on the short term. This laser has been developed for use in long range communications systems and is capable of operating in any position without affecting the operating characteristics.

The laser utilizes a master-oscillator, power-amplifier to achieve high power simultaneously with high stability and is capable of providing up to 38 watts of single-frequency light in the TEM_{00q} mode. A temperature-controlled oscillator provides 5 watts of power at a single wavelength at 10.6 microns for an active plasma length of 50 cm. The amplifier utilizes a folded structure with a total optical path length of about 7 meters. DC excitation is used.

A second oscillator, identical to the first, was used to obtain relative frequency stability information by heterodyne techniques. Long-term stability, as determined by the thermal environment, was about ±3 parts in 10^7. The short-term stability varied between 5 parts in 10^{11} and 1 part in 10^9 over a 10 ms time interval. The short-term frequency stability depends strongly on the laser acoustical environment.

Experimental results are also presented on the effects of RF excitation, laser bore size, and gas mixture on the laser output.

Keywords: Frequency Stabilization, Mode Selection, Sealed-off System, Single Mode (TEM_{00}), Doppler Line Width, Effect of Tube Diameter

110. Inaba, H. and H. Ito: Observation of Power-Dependent Distortion of an Infrared Beam at 10.6 Microns from a CO_2 Laser During Propagation in Liquids. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 2, February 1968, pp. 45-48.

Abstract: This paper reports the first experimental verification of the existence of the self-induced effect of spread and serious distortion of the infrared beam from the CO_2 laser system at 10.6 microns when propagating in various liquids. The power-dependent shape of the laser beam after passage

through the liquid cell was visibly displayed on the Kalver film by virtue of the thermal development method originally invented by our laboratory. The phenomenon observed is considered as having a thermal origin due to the partial absorption of the infrared beam; yielding localized heating, and thereby thermal convection which causes a complex change of the refractive index around the beam passing through the medium. The interference fringes found in the distorted beam pattern are likely attributed to the spherical aberration in the thermal defocusing lens induced in the material by the laser beam itself.

Keywords: Visual Observation of CO_2 Laser Beam, Kalver Film, Distortion of CO_2 Laser Beam by Passage through Liquids

111. Caddes, D. E., L. M. Osterink, and R. Targ: Mode Locking of the CO_2 Laser. Applied Physics Letters, Vol. 12, No. 3, February 1, 1968, pp. 74-76.

Abstract: Mode-locking a CO_2 laser through the use of a GaAs intra-cavity acousto-optic loss modulator is reported. Also presented are the results of an analysis which includes the important effect of nonlinear saturation on the output power.

Keywords: Mode-Locking, GaAs Intra-cavity Modulator

112. Carbone, R. J.: Continuous Operation of a Long-Lived CO_2 Laser Tube. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 3, March 1968, pp. 102-103.

Abstract: A sealed-off CO_2 laser tube was operated with continuous, almost constant, power output at 10.6 microns for more than 1000 hours. A Ni cathode that was maintained at 300°C acted as a catalyst to regenerate CO_2 back into the tube from the oxygen and carbon monoxide formed in the discharge. By the time 1100 hours of operation had passed, 92 percent of the original CO_2 concentration was still available in the tube.

Keywords: Heated Nickel Cathode, Sealed-off System

113. Djeu, N., T. Kan, C. R. Miller, and G. J. Wolga: Sequential Q-Switching of Vibration-Rotation Transitions in the CO_2 Gas Laser. Journal of Applied Physics, Vol. 39, No. 3, March 1968, pp. 2157-2159.

Abstract: In this note the authors report the rotation of a diffraction grating end mirror to obtain sequential Q-switching of the individual vibration-rotation transitions in both the 9.4- and 10.6-micron bands of CO_2. This differs from conventional Q-switching, in that with this method each transition comes successively into resonance at a different time during one rotation of the grating. A controlled series of high-power pulses is emitted which may have practical applications in laser range finding. The sequential switching of molecular oscillation frequencies is particularly suitable for studies of relaxation processes in the laser.

Keywords: Q-Switching, Diffraction Grating End Mirror, Laser Rang Finding, Relaxation Processes

114. Rao, D. R., L. O. Hocker, A. Javan, and K. Knable: Spectroscopi Studies of 4.3 Micron Transient Oscillation in CO_2. Journal of Molecular Spectroscopy, Vol. 25, No. 3, March 1968, pp. 410-411.

Abstract: This paper reports an analysis of wavelength measuremen of 4.3 micron laser oscillations in CO_2, and suggests that these oscillations arise from $[10°2, 02°2]_1 \rightarrow [10°1, 02°1]_1$, vibrational-rotational transitions with a ΔB value of $0.0031 \pm 0.0001\,cm^{-1}$.

Keywords: Spectroscopy, 4.3 Micron Radiation

115. Warner, J.: Photomultiplier Detection of 10.6 Micron Radiation Using Optical Up-Conversion in Proustite. Applied Physics Letters Vol. 12, No. 6, March 15, 1968, pp. 222-224.

Abstract: Synthetic single-crystal proustite pumped with collimated pulsed ruby laser radiation has been used to convert 10.6 micron radiation to the visible. Measured values of photo conversion efficiency ($N_s/N_{ir} = 1.4 \times 10^{-6}$) and phase-matched bandwidth (540 Å at 10.6 microns) are in good agreement with theory.

Keywords: Parametric Up-Conversion, Conversion of 10.6 Micron Radiation to the Visible, Proustite, Photomultiplier Detection of 10 Micron Radiation

116. Oppenheim, U. P. and A. D. Devir: Determination of CO_2 Line Parameters Using a CO_2-N_2-He Laser. Journal of the Optical Society of America, Vol. 58, No. 4, April 1968, pp. 585-586.

Abstract: In order to increase the number of spectral lines available from a freely operating CO_2 laser, the authors have incorporated a frequency-discriminating device in the laser cavity, in the manner described by Moeller and Rigden. In this way, laser action was achieved for about 40 rotational lines in the (00°1-10°0) band.

Keywords: Frequency-Discrimination, Spectroscopy, Rotational Lines, CO_2 Spectral Line Parameters, Spectral Lines, Spectral Line Width, Pressure Broadening

117. Kindl, H., W. Leeb, and G. Schiffner: Dependence of CO_2 Laser Discharge Current on Laser Action. Proceedings of the IEEE, Vol. 56, No. 4, April 1968, pp. 781-782.

Abstract: Discharge current changes and variations in side light of a CO_2-N_2-He laser due to chopping of laser action are investigated experimentally. Depending mainly on CO_2 partial pressure, an increase or a decrease of current is observed if laser action is stopped.

Keywords: Discharge Current Changes due to Lasing, Side Light Changes due to Lasing

118. Witteman, W. J. and H. W. Werner: The Effect of Water Vapour and Hydrogen on the Gas Composition of a Sealed-Off CO_2 Laser. Physics Letters, Vol. 26A, No. 10, April 8, 1968, pp. 454-455.

Abstract: A mass spectrometer analysis of the gas composition of a CO_2 laser as a function of operating time is presented. It is shown that the production of CO depends on the hydrogen concentration of the gas mixture.

Keywords: Mass Spectrometric Analysis, Sealed-off System, Additives (H_2, H_2O)

119. Wisniewski, E. E., M. E. Fein, J. T. Verdeyen, and B. E. Cherrington: Thermal Production of a Population Inversion in Carbon Dioxide. Applied Physics Letters, Vol. 12, No. 8, April 15, 1968, pp. 257-258.

Abstract: A population inversion for the 00°1-10°0 (10.6 micron) transition in CO_2 has been created by resonant collisional transfer of excitation from thermally excited N_2.

Keywords: N_2 Resonant Collisional Transfer, Thermal Excitation of N_2

120. Wood, O. R. and S. E. Schwarz: Passive Mode Locking of a CO_2 Laser. Applied Physics Letters, Vol. 12, No. 8, April 15, 1968, pp. 263-265.

Abstract: Self-locking of longitudinal cavity modes has been observed in a CO_2-N_2-He laser with an SF_6 absorber inside the cavity. Pulses as short as 20 nsec, with peak power in the range 10^4-10^5 W, have been obtained. Pulse trains longer than 100 microseconds have been observed. Operation is repetitive at millisecond intervals.

Keywords: Mode Locking, SF_6 Absorber, Doppler Line Width

121. Hill, A. E.: Multijoule Pulses from CO_2 Lasers. Applied Physics Letters, Vol. 12, No. 9, May 1968, pp. 324-327.

Abstract: A high voltage transient pumping technique is reported whereby 5-J 200-kW CO_2 laser pulses have been produced in a 3-inch-diameter, 8-foot discharge tube. This device, operating at repetition rates of 35-100 pulses per second, produced 210 W maximum average power. Similar devices of 1-inch through 6-inch diameters indicate that, unlike continuous-wave CO_2 lasers, this pulsed system may be extended at least to 6-inches diameter and/or total pressures in excess of 60 Torr, without severe loss of plasma uniformity. Preliminary scaling experiments indicate that further increases in peak and average power might be achieved.

Keywords: Pulsed Output, Multijoule Pulses

122. Djeu, N., T. Kan, and G. T. Wolga: Gain Distribution, Population Densities, and Rotational Temperature for the (00°1-10°0) Rotation-Vibration Transition in a Flowing CO_2-N_2-He Laser. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 5, May 1968, pp. 256-260.

Abstract: Small-signal gain coefficients in a flowing amplifying mixture of CO_2-N_2-He were measured in 46 individual rotation-vibration transitions in the P- and R-branches of the (00°1-10°0) band in CO_2. The resulting gain distribution as a function of J was in agreement with a Boltzmann distribution of population among the rotational levels of each vibrational state. The physical parameters characterizing the CO_2 laser levels were found to be:

$$\frac{N_{00^\circ 1}}{N_{10^\circ 0}} = 2.27; \qquad \frac{N_{00^\circ 1}}{N_{total}} \geqq 0.17;$$

$$\frac{N_{10^\circ 0}}{N_{total}} \geqq 0.08; \qquad T = 340^\circ K$$

where N_{total} is the number of CO_2 molecules in the amplifying medium. The operating mixture was characterized by the following partial pressures and flow velocity: $p(CO_2) = 0.65$ Torr; $p(N_2) = 1.40$ Torr; $p(He) = 2.9$ Torr; $v = 192$ cm/sec.

Keywords: Gain Distribution Function, Population Densities, Rotational Temperature, Small-signal Gain

123. Clark, P. O. and J. Y. Wada: The Influence of Xenon on Sealed-Off CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 5, May 1968, pp. 263-266.

Abstract: The role of xenon as a gas additive in sealed-off CO_2-N_2-He and CO_2-He lasers has been investigated. Maximum output power and maximum efficiency are increased by about 25 percent and 15 percent, respectively. The operating conditions of the lasers shift to higher currents with an accompanying 20 to 25 percent decrease in discharge voltage. An operating life of 2800 hours has been demonstrated by a sealed-off CO_2-Xe-He laser. Comparative measurements

have been made of the electron temperature and electron density in CO_2-N_2-He and CO_2-Xe-He laser discharges. With gas pressures and current adjusted for optimum laser performance, CO_2-Xe-He discharge is characterized by a higher (approximately 45 percent) electron density.

Keywords: Additive (Xe), Sealed-off System, Long Lifetime

124. Carswell, A. I. and J. I. Wood: High-Speed Reactive Q-Switching in CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 5, May 1968, pp. 294-296.

Abstract: A technique is described whereby CO_2 lasers can be Q-switched to provide high-frequency-output pulse repetition rates. The method is based on the use of a rotating transparent plate within the optical cavity of the laser to vary the optical path length between the mirrors. Measurements show that with an NaCl plate, pulse repetition rates in excess of 200 kHz can be achieved. Pulse widths are typically a few hundred nanoseconds. Maximum repetition rates and peak power output depend on the specific discharge parameters.

Keywords: Q-Switching, Nanosecond Pulse Widths

125. Gordiets, B. F., N. N. Sobolev, and L. A. Shelepin: Kinetics of Physical Processes in CO_2 Lasers. Soviet Physics - JETP, Vol. 26, No. 5, May 1968, pp. 1039-1045.

Abstract: A method of computing vibrational level populations in CO_2 lasers is proposed. The method postulates the introduction of a vibrational temperature T_i for each vibrational mode. The vibrational and gas temperatures are determined by the equations of the vibrational energy balance and thermal conductivity. Population inversion is computed as a function of the relative concentration of CO_2, N_2, and He, total pressure, free electron density, and discharge tube radius. The effect of these parameters on the laser output power is also evaluated. The obtained relationships coincide qualitatively with experimental curves. A quantitative agreement is also present within the limits of accuracy of the investigated model.

Keywords: Computation of Vibrational Energy Level Population, Computation of Population Inversion

126. McAvoy, N., H. L. Richard, J. H. McElroy, and W. E. Richards: A 10.6-Micron Laser Communication System Experiment for ATS-F and ATS-G. Goddard Space Flight Center, Greenbelt, Maryland, NASA TM X-524-68-206, May 1968.

Abstract: The purpose of the coherent laser satellite-to-satellite experiment proposed for the ATS-F and ATS-G program is to use the present laser state-of-the-art to establish the feasibility and value of optical space communications. Identical 23-pound transceivers will be placed on ATS-F and -G, each consuming 20 watts of prime power. Information will be imposed on a frequency-modulated 10.6-micron carbon-dioxide laser beam within a 30-MHz bandwidth. A superheterodyne receiver with a 12.6 dB noise figure will be used at each end of the link. A 5-inch-aperture optical antenna with a 100 dB antenna gain and a 400 mW carrier, will provide a 28 dB signal-to-noise ratio.

The experiment, incorporating components and subsystems tested in the laboratory and field, will be the first complete laser space communications link. By establishing the above-mentioned weight, power levels, signal-to-noise ratio, and bandwidth, and by testing its performance in actual space operation, the engineering parameters necessary to meet NASA requirements for future applications to deep-space distances or for earth-orbital missions with information capacity far greater than the 30 MHz proposed here can be realistically predicted. A single 5 inch viewing port through the skin of the 30 foot antenna, used for both transmitting and receiving, will not interfere with the structure of the antenna pattern. Optical auto-tracking, sufficiently accurate to benefit from the intrinsic high gain of the optical antenna, will supplement pointing of the optical axis with respect to the ATS geostabilization.

As ATS-F and -G plans become more specific, the experiment may be integrated into other communication links: for example, S-band from Nimbus to ATS-G; 10.6 microns from ATS-G to ATS-F; and X-band from ATS-F to a data-acquisition facility. This approach to the ATS-F and -G programs will pave the way for an operational integrated orbital network. It will provide baseline design information on the use of an optical link in the planned Data Relay

Satellite (DRS) and the Earth Resources Technology Satellite series (ERTS).

The experiment will be conducted in two phases: The first, establishment of an optical data link between ATS-F and a ground terminal, will fulfill most of the technical objectives. It includes the use of a mobile laser ground station whose equipment will be essentially a prototype of the ATS-G flight package. The second phase will be to establish a high data-rate optical link between ATS-F and -G.

Keywords: Satellite Communications Experiment, ATS Satellite, Heterodyne Receivers, Frequency Stabilization

127. Bletzinger, P. and A. Garscadden: Influence of Xenon on CO_2 Laser Plasmas. Applied Physics Letters, Vol. 12, No. 9, May 1, 1968, pp. 289-291.

Abstract: Measurements are reported showing the influence of xenon on the discharge properties of CO_2 lasers. Small admixtures of xenon lower the electron temperature considerably and it is possible to operate the CO_2 laser without nitrogen and with little decrease in output power for low flow rates or sealed-off operation. The influence of added CO is reported briefly. It is proposed that direct electronic excitation to the vibrational levels of CO and consequent energy transfer from the CO ($\nu = 1$) to the CO_2 upper laser level is the most important mechanism when N_2 is absent.

Keywords: Additive (Xe), Sealed-off System

128. McElroy, J. H. and H. E. Walker: Measurements on a Near-Confocal Optical Resonator. Applied Optics, Vol. 7, No. 6, June 1968, p. 1235.

Abstract: Recent work with the carbon dioxide laser and other lasers operating in the far ir has frequently involved the use of aperture coupled optical resonators. While restricted analyses of such resonators have been published, no experimental results of a study of these resonators have been published. The purpose of this letter is to report the results of measurements made on a CO_2 laser employing a near-confocal optical resonator. The multimode power output

was measured for seven coupling hole diameters ranging from 7.7% to 54% of the inner diameter of the laser tube These measurements were repeated for a number of mir separations at and near the confocal spacing.

Keywords: Near-confocal Resonator, Aperture (Hole) Coupling

129. Freed, C.: Design and Short-Term Stability of Single-Frequency CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 6, June 1968, pp. 404-408.

Abstract: This paper describes a family of sealed-off, single-frequency, TEM_{00q}-mode CO_2 lasers with output powers up to 15 watts. Short-term frequency stability measurements of the beat note of two free-running lasers in typic laboratory setups are discussed thereafter. The preliminary measurements indicate a short-term stability of at 5 parts in 10^{12} for an observation time of 0.05 seconds, and about 5 parts in 10^{13}, disregarding the discrete spec lines resulting from 60-Hz modulation by power supply ripple. One or two orders-of-magnitude improvement is predicted, leading to the possibility of measuring the line width limit imposed by quantum noise.

Keywords: TEM_{00q} Mode, Frequency Stabilization, Sealed-off Syste Linewidth Measurement, Beat Frequency Spectrum

4. ALPHABETICAL LISTING OF AUTHORS

The following listing includes all authors from the previous section of th document. The reference numbers to the right of the alphabetical listing ref to the chronological reference number assigned previously.

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5. ALPHABETICAL INDEX OF KEYWORDS AND PHRASES

In the third section of this document a chronological listing of references was provided. Each of these references was assigned a number in accordance with its chronological order. The following index of keywords and phrases taken from the third section uses those chronological reference numbers to locate the articles related to a particular keyword or phrase.

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